TRANSACTIONS

OF THE

American Foundrymen's Association

Proceedings of the

Thirty-Fourth Annual Meeting

Cleveland, Ohio

May 12 to 16, 1930

VOLUME XXXVIII

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of the

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Summary of the Proceedings of the 34th Annual Meeting

THE thirty-fourth annual convention of the American Foundrymen's Association and the twenty-third exhibit of foundry equipment and supplies was held in the Public Auditorium of Cleveland, May 12 to 16, 1930. The registered attendance listed 7,745 men and 289 ladies, this attendance exceeding that of any previous convention by a considerable margin.

The commercial exhibits totaled 248, occupying 77,407 square feet of space. These were augmented by 44 technical and educational exhibits occupying 6,160 square feet of space, including exhibits of A. F. A. committee activities, engineering schools and colleges, government bureaus and technical and trade associations.

Cooperating organizations in the non-commercial exhibits section included the following:

American Society for Testing Materials
American Society of Mechanical Engineers
Foundry Equipment Manufacturers' Association
Gray Iron Institute
Malleable Iron Research Institute
National Founders' Association
National Safety Council
Ohio Foundries Association
Steel Founders' Society of America
U. S. Bureau of Mines
U. S. Bureau of Standards

Engineering and trade schools which exhibited the work of their respective foundries and pattern shops included the following:

Agricultural and Mechanical College of Texas
Carnegie Institute of Technology
Cleveland Foundry Trade School
Cornell University
Georgia School of Technology
Louisiana Polytechnic Institute

Michigan State College
Ohio State University
Purdue University
Rochester, N. Y., Shop School
Rose Polytechnic Institute
University of Illinois
University of Iowa
University of Michigan
University of Nebraska
University of North Dakota
University of Pennsylvania

Organizations which entered apprentice material in the iron and steel molding contests and in the pattern-making contest included the following:

American Manganese Steel Co., Chicago Heights, Ill.
Birdsboro Steel Foundry & Machine Co., Birdsboro, Pa.
Brown & Sharpe Mfg. Co., Providence, R. I.
East Chicago, Ind., Foundry Group
General Electric Co., Lynn, Mass.
General Electric Co., Schenectady, N. Y.
Milwaukee Branch, National Metal Trades Association
Quad City Foundry Group
Westinghouse Electric & Mfg. Co., So. Philadelphia, Pa.

Ladies' Entertainment

The ladies' entertainment, under the auspices of the Cleveland Foundrymen's Committee on Arrangements, consisted of auto trips, shopping tours and a luncheon party at the Shaker Heights Country Club. The ladies also participated in the reception and dance held on Monday evening, May 12, in the club rooms of the Public Auditorium, and in the annual A. F. A. banquet on Thursday evening, May 15, at the Hotel Cleveland.

Exhibitors' Dinner

The third annual exhibitors' dinner was held at the Hotel Statler on Tuesday evening, May 13. Harry W. Standart, Northern Engineering Works, Detroit, and president of the Foundry Equipment Manufacturers' Association, presided. S. T. Johnston, S. Obermayer Co., Chicago, and past president of the A. F. A., acted as toastmaster. A program of short speeches and diversified entertainment was provided.

Technical Sessions

The program of meetings was one of the most extensive ever scheduled, as the increasing attendance at the meetings necessitated providing sessions to meet the needs of all the various branches and interests of the industry. The sessions were of three classes, namely:

Technical papers discussions
Round-table luncheon meetings
Shop-operation course discussions

The technical papers, 39 in all, were presented at the following 14 sessions:

Cast Iron	3 meetings,	11 papers
Nonferrous	2 meetings,	8 papers
Steel	1 meeting,	4 papers
Malleable	1 meeting,	3 papers
Management	2 meetings,	2 papers
Costs	1 meeting,	2 papers
Sand Control	1 meeting,	2 papers
Apprentice Training	1 meeting,	2 papers
Materials Handling	1 meeting,	3 papers
General	1 meeting,	2 papers

Round-table luncheon meetings were held for the steel, malleable and nonferrous groups. Shop-operation courses were held for the steel, nonferrous and gray iron practical shop operators and workers.

Opening Session and Annual Business Meeting
Monday, May 12, 2:00 p. m.

The opening session and annual business meeting was called to order by President Fred Erb, Erb-Joyce Foundry Co., Detroit, who then called upon the chairman of the Cleveland Committee, Walter L. Seelbach, Forest City-Walworth Run Foundries Co., Cleveland, to introduce the mayor of Cleveland, John Marshall.

Mayor Marshall, in welcoming the members of the Association to Cleveland, spoke as follows:

> MAJOR JOHN MARSHALL: I appreciate indeed the privilege of coming here today, representing the city, to extend to this group of men engaged in a fundamental industry the welcome of Cleveland.

As I understand it, you really inaugurated our Public Auditorium, holding the first very large convention and exhibition in that main building. We have since erected as an addition to the main hall the Annex. Your organization has grown so large that you require not only the main hall but the annex and the wings as well.

An address of welcome by the mayor always is more or less of a formality, and yet I would like somehow to have you feel that in this instance it is intended to be a real expression of our sincere interest in your gathering, in the subjects you are to discuss, and in the purpose for which you have come to our city.

I know that you have ahead of you a week of instruction and discussion of the matters which affect you in a technical and business way, which is bound to be beneficial to you, and I know will be to the city, which is a large center of your industry. Everything will be done to make you feel that Cleveland really appreciates the honor of having you here during this week.

Mr. Seelbach then welcomed the guests and members of the Association on behalf of the Cleveland foundrymen. President Erb responded to the welcoming addresses and then presented his presidential address. *(This address will be found on page xxiii.)*

Vice-President N. K. B. Patch, Lumen Bearing Co., Buffalo, was next called upon to present a report of the Committee on Correlation of Divisional Activities, of which he was chairman. This report was read and placed on record.

The report of Executive Secretary C. E. Hoyt was next presented.

Secretary Hoyt then reported that at the meeting of the Board of Directors on Sept. 12, 1929, the Board had unanimously voted to recommend to the members of the Association the election of Past-President S. T. Johnston to Honorary Membership in the American Foundrymen's Association. Vice-

President Patch moved that the resolution of the Board be approved by the meeting. This motion, being duly seconded, was unanimously carried. Past-President Johnston then arose and expressed his appreciation of this action of the Association.

A cablegram of greetings from the Institute of British Foundrymen was read by Secretary Hoyt. This message read as follows:

> "The Institute of British Foundrymen send greetings to the American Foundrymen's Association with best wishes for a successful meeting."
>
> (Signed) Wesley Lambert,
> *President,* I. B. F.
>
> (Signed) T. Makemson,
> *Secretary,* I. B. F.

President Erb then appointed as members of a committee on resolutions the following:

B. H. Johnson, *Chairman*
F. W. Kirby
H. S. Simpson

Secretary Hoyt then read a resolution which had been prepared by a conference to consider foundry education in engineering schools. This resolution was as follows:

> *Whereas,* the A. F. A. has been questioned concerning the advantages of foundry training for engineers by the head of the department of industrial engineering of one of the state colleges—who states:
>
> "At the present time there is a serious feeling that the foundry is a relatively less important unit of our productive equipment and that it is becoming more so owing to the replacement of castings by forgings, steel stampings and steel shapes assembled by welding"—it is the sense of a committee appointed to consider this question, that:
>
> First, the foundry has not become and is not becoming a relatively less important unit of industry, but on the contrary, castings are an increasingly important engineering product;
>
> Second, that industry sustains an economic loss due to the lack of foundry knowledge on the

part of the engineer designer in the manufacture and application of the use of castings;

Third, it is recognized that a revolutionary development in the design of equipment and apparatus is taking place with which manufacture has kept pace, and that economic consideration must determine the character of product required for any structural detail.

Therefore, the committee recommends that the A. F. A. urge all schools of engineering to provide the medium by which students of engineering may acquire as complete knowledge of the foundry industry—in all its phases as relates to the design, manufacture and use of castings—as time and proper facilities will permit.

This committee recognizes that all colleges of engineering do not have the necessary facilities. There are means, however, for the training of students through cooperative effort between the colleges and industries, and this committee recommends that the A. F. A. lend its aid to the development of plans for such cooperation.

This committee, in consideration of the above findings and recommendations, also recommends that the A. F. A. establish a standing committee for the study of foundry education in cooperation with engineering colleges.

Respectfully submitted,

D. M. Avey, *Chairman*
J. H. Lansing
Enrique Touceda
P. R. Hall
C. E. Bulinger
E. A. Steinfurth
R. F. Harrington
E. F. Cone
D. G. Anderson
B. H. Johnson
F. A. Lorenz, Jr.
H. S. Falk

Secretary Hoyt moved that the foregoing resolution be adopted. This motion was seconded and, after D. M. Avey, *The Foundry,* Cleveland, as chairman of the conference reviewed its purposes, the motion was approved and referred to the Board of Directors for subsequent action.

President Erb then called upon Secretary Hoyt to read the report on the election of officers and directors of the Amer-

ican Foundrymen's Association for the year 1930-31. This report was as follows:

SECRETARY C. E. HOYT: In accordance with the provisions of the by-laws, a duly constituted Nominating Committee of the American Foundrymen's Association, at a meeting held in Cleveland on Jan. 13, 1930, nominated the following:

For President, to serve one year:

N. K. B. Patch, Secretary,
Lumen Bearing Co., Buffalo.

For Vice-President, to serve one year:

E. H. Ballard, General Foundry and Pattern Shop Superintendent,
General Electric Co., West Lynn, Mass.

For Directors, each to serve three years:

C. S. Anderson, Vice-President and General Manager,
Belle City Malleable Iron Co., Racine, Wis.

H. R. Culling, Vice-President,
Carondelet Foundry Co., St. Louis.

Fred Erb, President,
Erb-Joyce Foundry Co., Detroit.

R. M. Maull, Treasurer,
Tabor Mfg. Co., Philadelphia.

D. M. Scott, Vice-President,
The Symington Co., Rochester, N. Y.

The report of the Nominating Committee was then submitted by letter to all members, in accordance with the provisions of the by-laws, and as there have been no other nominations for officers or directors in the manner provided for, it will be in order for this meeting to declare the nominees named above as elected to the offices for which they were nominated, they to take office in accordance with the provisions of the by-laws.

S. C. Vessy, W. W. Sly Mfg. Co., Cleveland, moved the election of officers and directors as given in the foregoing report. The motion was seconded and carried.

There being no further business, the meeting was adjourned to reconvene at 4:00 p. m., Thursday, May 15.

Adjourned Annual Business Meeting
Thursday, May 15, 4:00 P. M.

President Fred Erb presiding.

B. H. Johnson, R. D. Wood & Co., Philadelphia, chairman of the Committee on Resolutions, presented the following resolutions, which were unanimously adopted:

> Cleveland, for the fourth time in the annals of the American Foundrymen's Association, has been the scene of the greatest and most successful convention and exhibition relative to the foundry industry ever held.
>
> The City of Cleveland has well lived up to its reputation as a convention city. The untiring zeal and generous hospitality of the people of this great industrial community, one of the greatest foundry centers of the world, with its unsurpassed arrangement of convention buildings, erected through the foresight of its enterprising citizens, the facilities for caring for the wants of the thousands of visitors to this convention, have gone far to make possible the marvelous success that this meeting and exhibition has attained.
>
> *Therefore, Be It Resolved:* That the American Foundrymen's Association extend its keen appreciation to the people of the City of Cleveland, represented by its Mayor and city government, the Chamber of Commerce, and the various committees, who through their splendid efforts have so adequately provided for the entertainment of its members and guests.
>
> That the Association commend the manager of the Auditorium and the members of the staff for their splendid cooperation and the efficient manner in which all details for the convention and exhibit have been carried out.
>
> That the Association offer its felicitation to and admiration for the ladies of the reception sub-com-

mittee, who by the generous contribution of their time, and by their gracious cordiality, have contributed so wonderfully to the entertainment and comfort of their guests.

That the Association commend the hotels for their interest in the success of the convention, and for their sincere cooperation in the various exigencies arising from a meeting of this kind.

That the appreciation of the Association be extended to the Press for its efficiency and care in the dissemination of news.

That the members of the Association commend its officers and directors for their parts in completing the numberless details connected with the success of this convention and exhibition, and especially that due praise be extended to its President, Fred Erb, its Vice-President and President-Elect, N. K. B. Patch, its Executive Secretary, C. E. Hoyt, and its Technical Secretary, R. E. Kennedy, due note being made of the record number, variety and quality of the exhibits, and the high class of the technical sessions.

That the Association extend its appreciation to the authors of the various papers presented at the technical sessions, recognizing the great amount of thought and effort required in their preparation.

That a moment in silent retrospection be observed by this meeting in memory of those departed members who have contributed so much toward the success of the Association, especially our late lamented associate, H. Cole Estep, who by his untiring effort for the Association, and by his loving personality, endeared himself to all.

That it be ordered by the Association that knowledge of this Resolution be imparted to those concerned.

Respectfully submitted by

RESOLUTIONS COMMITTEE

B. H. JOHNSON, *Chairman*
F. W. KIRBY
H. S. SIMPSON

APPRENTICE CONTESTS

The secretary of the Committee on Apprentice Training, R. E. Kennedy, then reported on the decision of the judges in the various apprentice contests held. The recommendations for winners of the contest prizes were as follows:

Steel Molding Contest

1st Prize: Wm. Norton, Hubbard Steel Foundry, East Chicago, Ind.

2nd Prize: Clarence Janes, Hubbard Steel Foundry, East Chicago, Ind.

3rd Prize: Ralph Adams, Birdsboro Steel Foundry & Machine Co., Birdsboro, Pa.

Gray Iron Molding Contest

1st Prize: Moroni Heap, Brown & Sharpe Mfg. Co., Providence, R. I.

2nd Prize: Wm. Fielding, General Electric Co., West Lynn, Mass.

3rd Prize: Everett Field, Rock Island Plow Co., Rock Island, Ill.

Pattern Making Contest

1st Prize: Peter Walzer, General Electric Co., West Lynn, Mass.

2nd Prize: Chas. Deak, Jr., American Steel Foundries, East Chicago, Ind.

3rd Prize: Leon Dionne, American Manganese Steel Co., Chicago Heights, Ill.

On presentation of this report, a motion was made that it be accepted and approved. The motion was seconded and unanimously carried.

There being no further business, President Erb declared the final adjournment of the 1930 business meeting.

Session No. 2—Foundry Costs
Tuesday, May 13, 10:00 A. M.

Chairman, A. E. Hageboeck, Frank Foundries Corp., Moline, Ill. Vice-Chairman, J. L. Wick, Jr., Falcon Bronze Co., Youngstown, Ohio. The first paper presented was:

A Cost System for Gray Iron Foundries, presented by J. L. Carter, Sacks-Barlow Foundries, Inc., Newark, N. J. The cost system presented by Mr. Barlow was the standard cost system of the Gray Iron Institute.

Following the presentation of the gray iron cost system, J. L. Wick, Jr., assumed the chair and called upon C. S. Humphrey, Westco-Chippewa Pump Co., Davenport, Iowa, to report on the organization of the nonferrous cost group.

Session No. 3—Malleable Iron
Tuesday, May 13, 10:00 A. M.

Chairman, J. H. Lansing, Danville Malleable Iron Co., Danville, Ill. The following report and papers were read:

Report of A. F. A. Committee on Malleable Iron Specifications, presented by Scott Mackay, Chairman, A. F. A. Malleable Iron Division.

Continuous Melting Process as Applied to Malleable Iron, by B. R. Mayne, Saginaw Malleable Iron Division, General Motors Corp., Saginaw, Mich. In the absence of the author, this paper was presented by C. L. Joseph of the Saginaw Malleable Iron Division, General Motors Corp.

Factors Affecting Machinability of Malleable Cast Iron, by H. A. Schwartz, National Malleable & Steel Castings Co., Cleveland.

Some Features of the Pulverized-Coal-Fired Air Furnace, by E. F. Wilson, Jefferson Union Co., Lockport, N. Y.

The report of the committee recommended that consideration should be given by A. S. T. M. Committee A-7 on Malleable Iron to the adoption of another standard for malleable iron to cover the range of lower strength materials (the higher carbon range). It was moved and seconded that the report of the committee be approved, and on a vote of 22 to 8 the motion was carried.

Session No. 4—Malleable Iron Founding—Round Table Luncheon and Meeting, Tuesday, May 13, 12:15 P. M.

Chairman, P. C. DeBruyne, Moline Malleable Iron Co., St. Charles, Ill. Vice-Chairman, E. E. Griest, Chicago Railway Equipment Co., Chicago. No formal papers were read at this meeting, the discussion being limited to questions which were propounded by the members in attendance.

Session No. 5—Cast Iron Metallurgy
Tuesday, May 13, 2:00 P. M.

Chairman, R. F. Harrington, Hunt-Spiller Mfg. Corp., Boston.

The following papers were read and discussed:

Effects on Cast Iron of Prolonged Heating at 800-1100 Degs. Fahr., by R. S. MacPherran and R. H. Krueger, Allis-Chalmers Mfg. Co., Milwaukee. (Read by R. S. MacPherran.)

Heat Treatment of Cast Iron, by F. J. Walls and A. Hartwell, Jr., Wilson Foundry & Machine Co., Pontiac, Mich. (Read by F. J. Walls.)

Blistering Tendency of Some Cast Irons When Enameled, by A. I. Krynitsky and W. N. Harrison, Bureau of Standards, Washington. (Read by A. I. Krynitsky.)

Session No. 6—Nonferrous Foundry Practice
Tuesday, May 13, 2:00 P. M.

Chairman, J. W. Bolton, The Lunkenheimer Co., Cincinnati. Vice-Chairman, H. F. Seifert, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa. The following report and papers were presented and discussed:

Report of A. F. A. Nonferrous Division, presented by J. W. Bolton, Chairman of the Division.

Deep-Etch Test of Brass, by W. F. Graham and L. A. Meisse, Ohio Brass Co., Mansfield, Ohio. (Read by W. F. Graham.)

Application of Ingot Metal to Production of Brass and Bronze, by Wm. Romanoff and C. O. Thieme, H. Kramer & Co., Chicago. (Read by Wm. Romanoff.)

Overcoming Alloy-Ingot Troubles in the Brass Foundry, by Wm. E. Paulson, Thos. Paulson & Son, Inc., Brooklyn, N. Y.

Session No. 7—Management
Wednesday, May 14, 10:00 A. M.

Chairman, E. H. Ballard, General Electric Co., West Lynn, Mass. The paper which was presented and discussed at this session was:

Personnel Management, by Dr. Harry Meyer, Frigidaire Corp., Dayton, Ohio.

Session No. 8—Gray Iron Foundry Practice
Wednesday, May 14, 10:00 A. M.

Chairman, Dr. H. W. Gillett, Battelle Memorial Institute, Columbus, Ohio. Vice-Chairman, Dr. E. E. Marbaker, Industrial Research & Engineering Co., Pittsburgh. The following papers were read and discussed:

Briquetting Cast Iron Borings, by H. Rayner, Dodge Bros. Corp. Division, Chrysler Corp., Detroit.

Continuous Melting from Cold Stock of Gray Iron in Electric Furnace, by N. L. Turner, Beach Foundry, Ltd., Ottawa, Canada.

Methods for Determining the Volume of Metals During Casting, by C. M. Saeger, Jr., and E. J. Ash, Bureau of Standards, Washington. (Presented by E. J. Ash.)

Session No. 9—Nonferrous Founding
Wednesday, May 14, 10:00 A. M.

Chairman, F. L. Wolf, Ohio Brass Co., Mansfield, Ohio. Vice-Chairman, R. L. Binney, Binney Castings Co., Toledo, Ohio. The following papers were presented and discussed:

(a) *Care and Maintenance of Fuel-Fired-Furnace Linings in the Nonferrous Foundry,* and (b) *Selection and Use of Refractory-Maintenance Cements in the Nonferrous Foundry,* by H. E. White, Lava Crucible Co. of Pittsburgh, Pittsburgh.

Stronger Aluminum Castings by Improved Foundry Practice, by T. D. Stay, E. M. Gingerich and H. J. Rowe, Aluminum Co. of America, Pittsburgh. (Presented by E. M. Gingerich.)

Progress in Die-Casting Industry, by Marc Stern, A. C. Spark Plug Co., Flint, Mich.

Session No. 10—Sand Control
Wednesday, May 14, 2:00 P. M.

Chairman, O. E. J. Abrahamson, Buffalo, N. Y. The following papers and committee reports were presented and discussed:

Sand Control as Viewed from the Producers' Standpoint, by W. W. Kerlin, Enterprise Sand Co., Pittsburgh.

Hot Permeability of Molding Sand, by W. M. Saunders and W. M. Saunders, Jr., Providence, R. I. (Presented by W. M. Saunders.)

Report of Committee on Tests of Foundry Sand, presented by Dr. H. Ries, Chairman of Committee on Tests.

Report of Sub-Committee on Mold-Hardness, presented by H. W. Dietert, Chairman of Sub-Committee on Mold Permeability and Hardness.

Report of Sub-Committee on Core Tests, presented by E. R. Young, Chairman of Sub-Committee on Core Tests.

Report of Committee on Grading Foundry Sands, presented by A. A. Grubb, Chairman of Committee on Grading.

Report of Committee on Conservation and Reclamation of Foundry Sands, presented by R. F. Harrington, Chairman of Committee on Conservation and Reclamation.

After being presented and discussed, the above-mentioned reports were approved by those present for acceptance as progress reports.

Session No. 11—Management
Wednesday, May 14, 2:00 P. M.

Chairman, B. H. Johnson, R. D. Wood & Co., Philadelphia. Two papers were presented, as follows:

The Value of Sales Analysis and Market Research, by J. P. Newman, McGraw-Hill Publishing Co., New York.

The Value of Cleanliness and Neatness in a Foundry, by Ed. Trapken, Sandusky, Ohio. In the absence of the author, the paper was presented by title.

Session No. 12—Steel Founding
Thursday, May 15, 10:00 A. M.

Chairman, D. M. Scott, Gould Coupler Co., Depew, N. Y.

The following report and papers were presented and discussed:

Reclaiming Steel Foundry Sands, by M. D. Pugh, Illinois Testing Laboratories, Inc., Chicago.

The Most Potent Variable, by Geo. Batty, Steel Castings Development Bureau, Philadelphia.

Notes on the Behavior of Sand Molds in Steel Foundries, by Paul L. Goodale, Commonwealth Division, General Steel Castings Co., Granite City, Ill. In the absence of the author, this paper was presented by R. A. Bull, Director, Electric Steel Founders' Research Group, Chicago.

Australian Steel Foundry Practice, by D. Clark, Adelaide, Australia. (Presented by title.) Exchange paper of the Australian Bureau of Steel Manufacturers.

Report of A. F. A. Representative on Joint Committee on Effect of Phosphorus and Sulphur in Steel, presented by R. A. Bull, A. F. A. representative on Joint Committee.

Session No. 13—Apprentice Training
Thursday, May 15, 10:00 A. M.

Chairman, D. M. Avey, *The Foundry,* Penton Publishing Co., Cleveland. The following committee report and papers were read and discussed:

Report of A. F. A. Committee on Apprentice Training, presented by C. J. Freund, Chairman of Committee on Apprentice Training.

Foundry Apprentice to Apprentice Foreman, by E. H. Ballard, General Electric Co., West Lynn, Mass.

Where Are the Young Foundrymen? by S. W. Utley, Detroit Steel Casting Co., Detroit.

Session No. 14—Steel Founding—Round Table Luncheon and Meeting, Thursday, May 15, 12:15 P. M.

Chairman, W. J. Corbett, Fort Pitt Steel Casting Co., McKeesport, Pa. Vice-Chairman, H. P. Evans, Hubbard Steel Foundry Co., East Chicago, Ind. This session was devoted to the informal discussion of steel foundry problems as brought up by the members present.

Session No. 15—Nonferrous Founding—Round Table Luncheon and Meeting, Thursday, May 15, 12:15 P. M.

Chairman, H. M. St. John, Detroit Lubricator Co., Detroit. Vice-Chairman, Wm. E. Ball, Edna Brass Mfg. Co., Cincinnati. This session was devoted to the informal discussion of nonferrous foundry problems as brought up by the members present.

Session No. 16—Gray Iron Metallurgy
Thursday, May 15, 2:00 P. M.

Chairman, H. Bornstein, Deere & Co., Moline, Ill. Vice-Chairman, R. F. Harrington, Hunt-Spiller Mfg. Corp., Boston.

The following papers were read and discussed at this meeting:

Carbon and Sulphur in the Cupola—Some Properties of Coke, by Jas. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.

Correlation of Tests for Cast Iron, by J. G. Pearce, Director, British Cast Iron Research Association, Birmingham, England. (Presented as the annual Exchange Paper of the Institute of British Foundrymen.)

Simplified Methods for Controlling the Production of Cast Iron, by L. F. C. Girardet, Saint Die, Vosges, France. (Exchange Paper of the Association Technique de Fonderie de France, the French Foundry Technical Association.) In the absence of the author, this paper was presented by J. W. Bolton, The Lunkenheimer Co., Cincinnati.

Session No. 17—Materials Handling
Friday, May 16, 10:00 A. M.

Chairman, D. G. Anderson, Western Electric Co., Chicago. The following papers were read and discussed:

Continuous Core Ovens, by D. B. Hill, Palmer-Bee Co., Detroit.

Materials Handling, by W. M. Booth, Syracuse, N. Y.

Reducing Materials-Handling Costs in the Jobbing Foundry, by F. D. Campbell, chief engineer of the Eastern Corporation, New York.

Session No. 18—General Foundry Practice
Friday, May 16, 10:00 A. M.

Chairman, E. F. Cone, Iron Age Publishing Co., New York. Vice-Chairman, Wm. Romanoff, H. Kramer and Co., Chicago. The following papers were read and discussed at this general session:

Some Considerations in Gating and Pouring Castings, by E. V. Ronceray, Ecole Superieure de Fonderie, Paris, France. In the absence of the author, this paper was presented by R. E. Kennedy, Technical Secretary, American Foundrymen's Association, Chicago.

Value of Analyses and Specifications for Core Oils, by J. A. Gitzen, Lindsay-McMillan Co., Milwaukee.

Induction Furnaces for Ferrous and Nonferrous Metals, by

Manuel Tama, Berlin, Germany. In the absence of the author, this paper was presented by G. H. Clamer, Ajax Metal Co., Philadelphia.

Crucible Furnace Melting Practice, by H. E. White, Lava Crucible Co. of Pittsburgh, Pittsburgh.

SHOP OPERATION COURSES

The three shop-operation courses, organized for the benefit of the practical shop man of the steel, gray iron and nonferrous foundries, were carried out according to the following schedule:

GRAY IRON

Session No. 1—Cupola Materials
Monday, May 12, 4:00 P. M.

Leader, C. J. Scullin, Alda Research Laboratories, Inc., St. Louis.

Session No. 2—Cupola Materials and Operation
Tuesday, May 13, 4:00 P. M.

Leader, R. S. MacPherran, Allis-Chalmers Mfg. Co., Milwaukee.

Assistant Leaders: Jas. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.; F. J. Walls, Wilson Foundry & Machine Co., Pontiac, Mich.

Session No. 3—Gating and Risering
Wednesday, May 14, 4:00 P. M.

Leader, H. W. Dietert, U. S. Radiator Corp., Detroit.

Assistant Leaders: E. M. Handley, Chain Belt Co., Milwaukee; Dr. Fritz Meyer, National Radiator Co., Johnstown, Pa.

Session No. 4—High-Test Irons, Alloy Additions and Heat Treatment, Thursday, May 15, 4:00 P. M.

Leader, H. Bornstein, Deere & Co., Moline, Ill.

Assistant Leader, F. B. Coyle, International Nickel Co., New York.

At this session a paper on *Chromium in Cast Iron* was read by T. F. Jennings, Utah Copper Co., Garfield, Utah.

STEEL

Session No. 1—Chipping, Grinding and Riser Removal
Tuesday, May 13, 4:00 P. M.

Leader, S. R. Robinson, Industrial Brownhoist Corp., Bay City, Mich.

Assistant Leaders: E. H. Ballard, General Electric Co., West Lynn, Mass.; James Suttie, American Steel Foundries, East Chicago, Ind.

Session No. 2—Core Room Practice
Wednesday, May 14, 4:00 P. M.

Leader, J. M. Sampson, General Electric Co., Schenectady, N. Y.

Assistant Leaders: H. E. Mooney, Falk Corp., Milwaukee; W. F. Wilson, American Steel Foundries, East Chicago, Ind.

Session No. 3—Practical Aspects of Heat Treating
Thursday, May 15, 4:00 P. M.

Leader, A. W. Lorenz, Bucyrus-Erie Corp., South Milwaukee, Wis.

Assistant Leaders: H. P. Evans, Hubbard Steel Foundry Co., East Chicago, Ind.; D. Zuege, Sivyer Steel Castings Co., Milwaukee; A. C. Jones, Lebanon Steel Foundry, Lebanon, Pa.

NONFERROUS

Session No. 1—Fuel Fired Furnace Melting
Tuesday, May 13, 4:00 P. M.

Leader, E. R. Darby, Federal Mogul Corp., Detroit.

Session No. 2—Induction-Type Electric Furnace Melting
Wednesday, May 14, 4:00 P. M.

Leader, R. W. Parsons, Ohio Brass Co., Mansfield, Ohio.

Session No. 3—Indirect-Arc-Type Electric Furnace Operation
Thursday, May 15, 4:00 P. M.

Leader, D. E. Broggi, Neptune Meter Co., Long Island, N. Y.

Annual Address

By the President, Fred Erb

Opening Session, Thirty-Fourth Annual Convention, Cleveland, Ohio.

President Fred Erb: As we review the accomplishments of science and industry during the first part of this century, we can only be gratified to note that our own business, the foundry industry, is keeping pace with the rapid strides that have been made in application of the developments in chemistry, in specialization—resulting in increased efficiency with its accompanying lessening of the strain on labor—and in the elimination of both physical and human waste.

We are living in a machine age, an age that is slowly but surely utilizing the resources of this great nation, through the application of improved techniques, in a way that is giving society the highest benefit for the least expenditure of both time and money. The brains of science have been applied to all types of industry, with the resulting elimination of blundering and mismanagement.

A Quarter Century of Progress

Twenty-five years ago we would not have had the courage even to imagine the changes that have been wrought in both production and distribution methods.

Who would have thought that a thousand automobiles could be turned out by a single factory in one day? Who would have dared to suggest that food could be furnished the consumer through the medium of such great chain store systems as the A. & P., Kroger, and others?

Who would have believed that systems of standardization in almost every branch of production could be so developed that efficiency and accuracy in production could be maintained and still have an ever-shifting and changing populace satisfied? And yet today we are right in the midst of this great developing system.

THE GROWTH OF SCIENCE

It was not so very long ago that scientific methods were considered too much in the realm of theory to serve as an aid to industry. Yet today science is the chief ally, the very basis of industrial methods. But the techniques of science have changed to a degree that parallels the changes in industry.

When Charles Darwin published his *Origin of Species* in 1859, a new life was born into this world. It is not so much what is contained in this *Origin of Species,* nor was it the publication of the work itself that gave rise to new efforts and new methods. But the technique utilized has served as a point of departure in all lines of endeavor.

First, we have the careful analysis of the problem in which the factors are separated out and studied in detail. All possible factors are considered.

On the basis of the examination of the numerous cases of isolated examples, a synthesis follows in which we have the drawing or formulating of laws of operation, based on hypotheses carefully established through the process of induction. What we actually have is the elimination of theory, the striking out of guess-work and the application of accuracy and efficiency based on sufficient observation and experience.

Since 1859 our physics and our chemistry have been changed almost beyond recognition. Our psychology has been entirely rebuilt. Since 1900 our social sciences have been literally created.

MARKED INDUSTRIAL CHANGES

The changes in industry are even more marked. Instead of individualism in production, we have cooperation. Instead of haphazard trial-and-error methods, we have sound scientific practices. Instead of slow, tedious hand work, we have machines, developed to an efficiency that the human factor could never attain.

Visualize a few of the results—the telephone, the automobile, the aeroplane, the radio. These comprise but a mere handful, important because of their commonness. The thousands of improvements in factory methods that enable these and hundreds of other socializing elements to be so constructed that they can be placed within the easy grasp of the average man, cannot even be considered here.

As members of American Foundrymen's Association, we can accept our share in these marvelous achievements. The foundry industry is keeping pace with the times. Applied science through the aid of the chemist and the engineer is keeping our business on a par with all others.

New methods have been evolved to meet the production requirements placed upon our industry by the development of the automobile and other commodities. Improved alloys, simplified methods, new machinery, concerted effort and many other factors—all have been constantly in the throes of change and development to meet the increasing demands of the times.

APPLIED SCIENCE IS KEYNOTE

These examples merely serve to indicate how we are answering the demands of the day. An alert, successful foundryman is one who has the ability to assimilate the present-day knowledge and put it into practice in terms of present-day needs. The detail man is essential to business, but the detail man is not the one who supplies the motive power that lies behind the industry.

Applied science is a modern thought. It is still more modern when applied to the foundry industry, for in spite of the progress we have made, we are young in the application of the practices of this machine age.

We are having our whole economic plan altered. Those who can meet this situation will build for themselves a business raised upon a foundation that can never crumble.

HARD WORK AND COOPERATION

It is not my purpose to discuss at this time the grumblings of the pessimists. We have some in our midst. No social group, no business, no industry can be entirely free of those who see nothing but failure ahead.

I cannot refrain from suggesting, however, that our industry holds little in store for the chronic shadow chaser.

We have our problems, to be sure. We face encroachments upon what seems to be our legitimate tramping ground. There will always be plenty of competition of one kind or another.

An adequate understanding of the problems we have to solve, coupled with a direct application of untiring effort as a

substitute for pessimism, will do more to aid us in the solution of our difficulties than anything else I know. No place in the sun can be either gained or maintained without knowledge and effort.

Pessimism will not gain a thing. False optimism will do no more. What we must do is put shoulders to the wheel and see that out of our combined efforts will come the success that is rightly ours.

HOW THE A. F. A. HAS HELPED

The American Foundrymen's Association is a technical association which has constantly aided the industry in developing new methods of meeting new conditions. The association has enabled knowledge to be disseminated for those who would take it. It has been the clearing house for a grouping of ideas to which all might come and from which all might benefit.

Our task is a never ending one. Although marvelous changes have been wrought in production, although undreamed results are being attained, although techniques of distribution have reached a peak never before realized, actually, only a start has been made along the road of industrial progress.

Our job is a big one. Through careful and keen observation, through scientific experimentation and the subsequent gathering of data, through the application to our industry of the improvements thus discovered, and above all through intelligent cooperation, we may hope to achieve in the years to come a large measure of the success that should be ours.

FOUNDRYMEN MUST MEET DEMAND

Civilization will continue to progress. Science will be forever discovering new processes, and production and distribution techniques must continue to evolve.

To us falls the burden of seeing that the foundry industry, functioning as it now is upon a solid economic basis, will continue to meet the demands of the times.

Let me close by reminding you that all foundrymen are, in a sense, engineers—technicians who must apply existing knowledge. The more carefully, accurately, efficiently and scientifically this application is made, the more greatness will our industry achieve.

Annual Banquet

American Foundrymen's Association
Hotel Cleveland, Cleveland, May 15, 1930

President Fred Erb presiding.

In opening the banquet proceedings, President Erb first introduced two overseas guests, J. G. Pearce, director of the British Cast Iron Research Association, Birmingham, England, and John T. Goodwin, general manager of the Sheepbridge Coal & Iron Co., Sheepbridge, a past president of the Institute of British Foundrymen. In responding to President Erb, Mr. Goodwin said in part:

MR. GOODWIN: Mr. President, Ladies and Gentlemen: I have the honor this evening to convey to you the kindest regards, the most affectionate welcome we can send over from our country to you, and the pleasure that we have in congratulating you and all those associated with you in this wonderful convention that you have here. We wish you the most hearty success in all the ventures that you are taking up on this side. We follow you with the utmost diffidence. We look upon you as being the leaders of the foundry work and foundry trade of the world.

The business relationship, the friendly feelings which exist between our country and yours, is such that we are proud of it, and long may it be that this state shall continue.

President Erb, in introducing as toastmaster Dr. Wm. E. Wickenden, president of Case School of Applied Science, made the following remarks:

PRESIDENT ERB: Members of the American Foundrymen's Association, Ladies and Gentlemen, Honored Guests: As members of the American Foundrymen's Association we are keenly aware of the debt that we owe to science. Every industry in the world must pay homage to those who have labored in the laboratories of our great scientific institutions that society might receive, through those who produce, a greater share of the comforts of life.

I sometimes wonder if people fully appreciate what the application of science to industrial methods really has meant to the world. Certainly we do not give much thought to all the wonders of this age while we are utilizing them. We walk into a darkened room; we press a button and a flood of light results. Do we stop to think about the thought and labor that is behind the little device which enables us to do that?

We drive our car along the street; we want to light a cigar or cigaret. We reach forward, press a handle and wait for the familiar glow, detach the lighter and in an instant are puffing away on a cigar or cigaret. We do not have to wait for the match to burn long enough to get results.

The process is simple enough. The means do not look complicated, yet days and months were spent in supplying us with that handy bit of comfort.

I might continue to enumerate examples of how the application of science to production has multiplied by thousands the number of factors that tend to bring comfort and ease to you and me, but this is not my job tonight. It seems quite fitting that when our thoughts are focused upon this very subject we should be fortunate to have a leader in this great world of scientific thought, a man who has spent years in developing this application of science to industry and in teaching others that they might enter the ranks of industry and, with the knowledge they have gained, take their part in the great progress of the world.

I am sure that all of you will agree that we are extremely fortunate in having with us tonight Dr. Wm. E. Wickenden, head of the Case School of Applied Science, who has honored us by consenting to act as our Toastmaster, who has also consented to address us on "Technical Education in Relation to the Foundry Industry," and to whom I shall now turn over the meeting.

DR. WICKENDEN: It seems a very happy omen for the new era of our American life that you who represent the industry which, in the popular mind, I have no doubt is highly suggestive of grime and grit and smoke, should be paying this very pretty compliment to art and to science. Possibly it betokens that the day has come when we have won some margin above the sweaty

labors of subduing the continent which Nature has given us and have some time to pursue these finer things of the spirit.

It is very gracious indeed of you to invite a college professor to leave the academic shades out at the cultural circle and to come down this evening and spend the time with men of important affairs.

This business of technical education is a very old business, as you see, but it has not always been held in high repute. The Greeks, you know, never were able to distinguish very closely between science and philosophy. Science was distinctly a speculative sort of business with them, and for applied science their greatest minds had but disdain.

They say that Archimedes, whom I suppose we should have to rank as "the Edison of the ancients," used to come around and apologize for his useful inventions, asking to have them excused as the recreation of a mind that had grown weary with pondering the abstract truths.

It is said that Plato once rebuked a mathematician when showing him some very ingenious invention he had, for having degraded so noble a mind to the level of a carpenter or wheelbarrower.

Old Seneca, the Roman Stoic, was said to have remarked that the invention of the Roman arch was a matter of no moment, for it should be a matter of indifference to a philosopher whether or not he had any sort of roof over his head.

These are different times, and we have come to hold science and the application of science in a very different sort of esteem. It is only in these recent days that we who claim a share in the training of men for the application of science to industry have been looked upon as being more than about half respectable among our educational confreres.

Of course, the thing that has done it all is the man who has passed through the discipline of science and has gone out and applied it to industry and has made good.

I was interested, a year or two ago, to trace some of the history of our great national engineering societies. We looked up the men in those organizations who were sixty or seventy years of age and found that perhaps only a quarter of them had had the benefit of a higher scientific and technical education. Then, by way of contrast and comparison, we looked up the records of the younger men, those under thirty, and found that

four-fifths of them had had the benefit of a scientific or technical education. Young men, trained in science, have gone into industry and have made good, and today they dominate our technical professions.

A great many people have said: "Oh yes, that may be so, but think of the large numbers of them who get discouraged and drop out, quit, give it up as a bad job." It was very interesting to look into that question and to find that only fifteen per cent of the young men who had gone through our colleges of applied science had drifted out of the technical professions, technical industries, into unrelated fields of work. They had made good.

Then we were very much interested, too, to get some check upon the earnings of these men and to find out whether they returned to society, by their service, the service for which they were compensated and for which their compensation is in some reasonable measure a good return on the investment which society has made in their training.

If you take a young man fresh from high school and propose to invest in him four more years of scientific and technical education, the probability is that it is going to cost somebody, sooner or later—not merely Dad, not merely the college treasury, but society in general—a sum of money which in the long run will probably amount to twelve or fifteen thousand dollars. If he had gone to work immediately upon stepping out of the high school with his diploma, he had a fair chance, an average chance, of earning in the aggregate throughout his active career (as nearly as statistics will tell us) about a total of $88,000.

Does he, by virtue of higher education, earn enough more to make a good return to society on his investment?

As an answer to that, suppose we were able to take one hundred typical graduates of our modern colleges of applied science and arrange them in a row in the increasing order of their prospective life earning power. We start at the bottom of the row and go up to number ten from the bottom. That man has a reasonable expectation of making a total earning in his active career of about $100,000. You see, he just about adds enough to what he might have earned had he gone to work after finishing his high school course—just about adds enough to pay the investment which society has made in his higher training.

Then we go up and find the man who stands twenty-fifth

from the bottom, and he has an expectation of earning in the aggregate of his active career, about $130,000.

Then we go up to the median man, the man in the middle of the procession, with as many ahead of him as there are behind him, and his prospect is that he will earn in his active life a total of about $200,000.

Then we go on up and take the twenty-fifth man from the top and his expectation is a total of $300,000 in his active career. Finally, we get up to the higher altitudes and take the man tenth from the top of the group; his expectancy for life earnings is $640,000.

With these facts to face us, we believe that it is time for the man of science and the engineer to throw away his inferiority complex and get rid of his poverty complex and apply better salesmanship to the selling of his services in the vastly under-saturated market in which those services are sold. It is a fact that American industry, taken by and large, is today very greatly under-recruited with men of the necessary scientific and technical training.

In some studies we were able to make a few years ago, we took the state of New Jersey. It was a compact, nearby institution, rather well organized for our purposes. We undertook to use it as a sample to find out what American industry needs in the way of recruiting from institutions of higher learning, emphasizing the sciences and their technical application.

The best estimates we could get were that American industry needs in its personnel not less than one man in fifty who has had the benefit of higher scientific and technical preparation—a need which at the present time is not one-third supplied. The present supply of men coming from our institutions would be not more than one-third enough to maintain that level of recruitment, even if we had obtained it.

The engineer, the man of science, the man of technical pursuits, is selling his services today in an under-saturated market. This, of course, is the reason why the recruiting line forms at the college and not at the employment office of industry. This is the reason why, under normal conditions, the average graduate of a college has perhaps two or three opportunities between which to choose, and the gifted man may have ten or a dozen opportunities between which to choose. This is the reason why the

starting salary in the last twenty-five years has trebeled and today has practically quadrupled.

I remember the day when a man thought he was lucky to start at forty dollars a month; very few men will step out of college into positions today at less than one hundred and fifty dollars a month. We are under-recruited with men of scientific and technical training throughout the length and breadth of our industries.

At the same time that we obtained this estimate of the man power that would be necessary to constitute a normal and reasonably balanced supply, we asked this question: If we could get them for your operating departments, how many men—who, after a period of experience, had had two years of higher training looking toward the distinctly practical pursuits of industry—would you like to have in your firm if you could find them?

The estimates came in indicating that they would like to have from six to eight and one-half per cent of the whole personnel of industry, men of that especially advanced form of practical training. That is a need which in our present sources of supply is not one-fiftieth supplied in the United States.

Taking a little closer look at some of our industries, and seeing what distribution we are making of the supply of man power that we have, through the courtesy of a great national research organization it was possible for us to take a very accurate sample of five of our principal industries—manufacturing industries concerned with the preparation of chemicals, making of paper-pulp products, a rubber product, electrical goods and the metal trades.

If we were able to call in all of the general officers of those five industries, we should find among them almost one man in two trained in our colleges and universities. If we were able to call in all of the engineering and technical officers of these industries and count them, we should find practically one man in two the product of our technical colleges and universities. If we were to call in the sales officers of these industries, we should find practically four men in ten the product of our colleges or technical universities.

We call in that great body of officers in charge of production and what do we find? We find one man in eleven drawn from our higher scientific and technical institutions. There is the

great and striking gap in the American processes of preparing and training and recruiting men for industry today.

We have in the hundred and fifty-odd scientific and technical colleges of the country today an admirable foundation for a national system of technical education, but a most incomplete structure. For every such institution we should have two or three which offer to men carefully chosen after the completion of a sound secondary education, after a period of introductory experience in industry, not less than two and possibly three years of training specifically directed to the practical direction of operating processes, the producing processes of industry. Among the great forward-looking industrial nations of the world at the present time, we are virtually the only nation that has failed to provide for that link in our chain of educational organization.

I lay that upon the consciences of this group because I suspect that that is a problem which comes rather closely home to you. If you look to the colleges and universities which carry men on through a period of four or more years of continuous education beyond the high school, expecting them to finish at the age of twenty-two or twenty-three, invested with the rights and insignia of professional degrees, invested with some sense of professional consciousness and of obligation to dignity, if you look to that group largely to go back to industry and begin in overalls and climb the ladder which leads from the work of production through foremanship, through the lesser grades of superintendency, to the higher grades of superintendency and management, I fear you may look in vain.

The college, by tradition, is an institution devoted to the training of men for the higher intellectual pursuits. If a young man is kept from active, responsible contact with the productive processes of industry until the age of twenty-three, the likelihood of starting him at the beginning of that ladder of line organization and operating responsibility is, I regret to say, a rather small one.

I think we must frankly face the fact that until we can match up these institutions which we now have with others which are specifically devoted to the task of preparing a great body of young men chosen from the working ranks of industry itself for the higher practical and higher operating responsibilities of industry, we may possibly be doomed to disappointment in our

hopes for the man power upon which every one of our industries depends.

There is another aspect of the thing as well. It has long been recognized, universally, that it is impossible for any man to complete a satisfactory education for technical and scientific professions in a college. Education for those purposes cannot be carried to completion in a college. We have before us a great task of adding another stage, another chapter built up on the base so that it can be produced within the college itself, carried on into the early years of the professional and industrial career, to capture the first five or ten years of the young man's participation in industry for the completion of his education.

It is a task which perhaps industry cannot do by itself. Certainly it is a task which colleges cannot do by themselves. It is a field of fascinating possibilities, of cooperation between industry and higher institutions so that we may capture young men after they have had a period of trial and have had "a run for their money" and have given some indication of what may be expected of them—that we may then capture them and bring them back into the processes of education for a higher stage of training than can possibly be given to them while they remain with us in the school itself. That, I think, is the great work which we must attack and attack together.

Dr. Wickenden then introduced John A. Penton, honorary member and the first secretary of the American Foundrymen's Association, who was to present the John A. Penton Gold Medal to H. A. Schwartz. Mr. Penton, in making the presentation, made the following remarks:

MR. PENTON: The American Foundrymen's Association has suggested that it might be appropriate for me on their behalf, to present to a distinguished metallurgist an evidence of their appreciation of his skill, his endeavor, his consecration to duty, his research and his hard work over the period of his life, to the industry with which he has been associated.

As a worker in the malleable castings field, he is one of those who has participated in the series of great discoveries that have made malleable castings what they are today in comparison

with what they were years ago. I remember quite well, among those manufacturers of malleable castings who were just breaking into the business and who perhaps were not as experienced as some others, when a tensile strength of 20,000 pounds was a pretty good thing—not 35,000, as I heard somebody say at a meeting of the malleable section the other day.

I remember when an elongation of five per cent was a pretty good elongation, while today, as a result of the study, the research, the experimentation, the development through the laboratory and the testing room of the materials that enter into the manufacture, the processes of annealing and all the other questions entering the manufacture of malleable castings, there has been a steady progress in the art until we have an average tensile strength of over 50,000 pounds extended over a vast period of time in thousands of tests in a great number of plants, and an elongation not of five or six or eight or ten or twelve or fifteen per cent, but even more, of a two-inch bar.

The gentleman to whom this medal is to be presented is one of these men who has been in the front rank in bringing about this result, and only those of you who know something about what that has meant to American industry, to American wealth in the last few years, know something of the debt of gratitude we owe to these great pioneers.

Therefore, it gives me a great deal of pleasure, on your behalf, to hand to this distinguished worker, this very sincere searcher in the field of science, this devoted student, this man of great accomplishment, this man whose record in the institutions with which he is connected has been most phenomenal—and I have to say that the institution with which he has been connected, the National Malleable Castings Co., also is the subject of some national gratitude because of the extent to which it has always been willing to support that kind of endeavor and then give to the world in great part the result of their investigation so that their competitors and others everywhere might enjoy the fruits of their own work—it gives me great pleasure not only on behalf of you as an organization, but it comes to me as a great personal gratification because of my friendship and personal appreciation of the gentleman whom I have known so long, respected so much and for whom I have such intense admiration, to present to him these evidences of your good will.

Mr. Schwartz, I am going to hand to you a very beautiful gold medal, presented to you by the American Foundrymen's Association for the reasons which I have just given, which I hope you may live long to preserve and, as long as you do live, that it will be a constant reminder of the associations you had while connected with this organization.

Mr. Schwartz responded as follows:

H. A. SCHWARTZ: Mr. Penton, for the first time in an experience of perhaps twelve or fifteen years addressing the American Foundrymen's Association, I find it difficult to say what I would like. Yet it is fitting that the recipient of this distinguished honor should express, although haltingly, his appreciation of what has been done for him, especially when the award is presented in person and bears the name of my old friend and almost neighbor, Mr. Penton, and when the proceedings are presided over by my newer Cleveland friend, Dr. Wickenden.

It is to be supposed that what you have thought worthy of reward has been the experimental work which has found expression for perhaps ten years in various technical publications. In that connection I would like to say what Mr. Penton has said, that there should join in that the name of the corporation which, by capital investments of perhaps a quarter of a million dollars and the maintenance of the facilities thereby provided for ten or twelve years, has made possible the work of which I have been perhaps a minor by-product.

I would like also to allude in this connection to a rather long list of my associates, most of them living, some dead, who actually did the work which it has been possible to bring to public notice in the publications of this society and others.

Again, Mr. Penton and Mr. President, and Members of the American Foundrymen's Association, the Board of Awards and the Directors, I thank you all.

Dr. Wickenden next presented Dr. Allen D. Albert, who delivered an address on the subject of "The New Economic Revolution." Following Dr. Albert's address the meeting was adjourned.

Reports on Membership and Finance and Minutes of Board Meetings

Following are presented the reports on Membership and Finances, and a record of all official acts of the Board of Directors and committees thereof from date of Sept. 13, 1929, to Dec. 31, 1930.

Membership

The accompanying chart giving the membership growth from date of organization in 1896 to Dec. 31, 1930, shows a sharp drop in 1899, a continued low level until 1906, the year the first organized exhibit was held and which gave an impetus that more than doubled the membership in two years. There was a falling off in 1911 and 1912, followed by an uninterrupted growth until the present time, except for a sharp decline in 1921, in which year no convention was held. This decline continued through 1922 and was followed by a marked improvement which resulted in a gain of 60 per cent in five years.

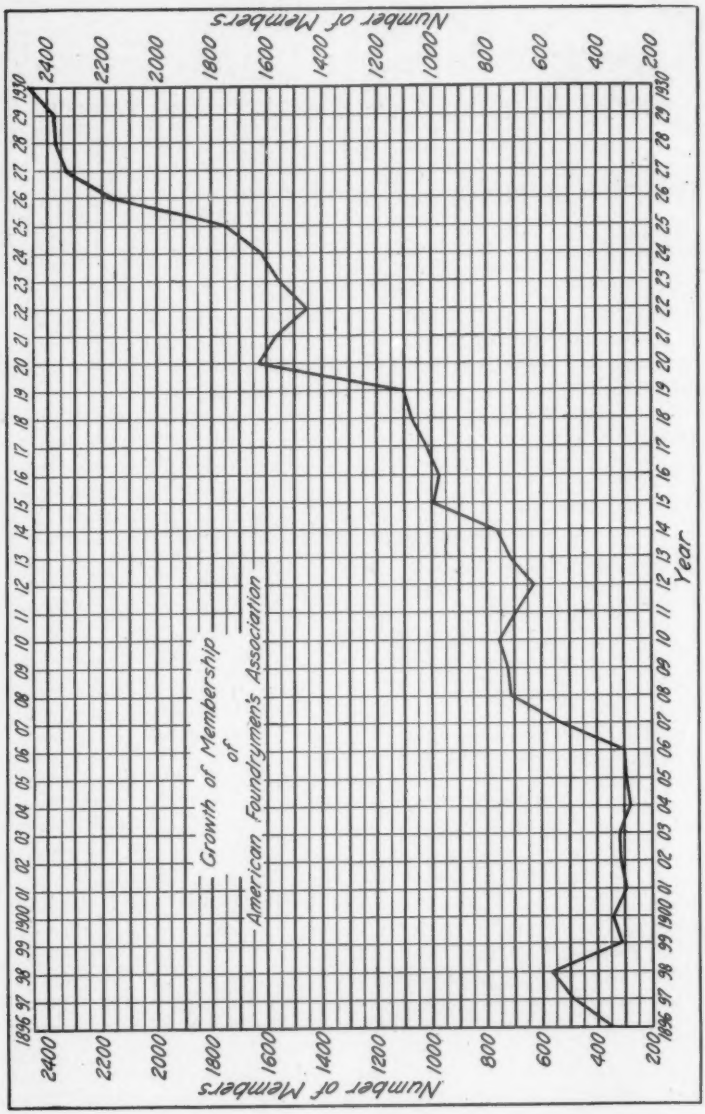
Following is the membership record for 1930:

Book membership Jan. 1, 1930		2,368
New members elected	299	
Resignations	112	
1929 delinquents dropped	73	
Removed by death	5	
Total	190	
Net gain during 1930		109
Book membership Jan. 1, 1931		2,477
Per cent gained		4.5%

In the report of the Secretary-Treasurer at the 1929 annual meeting it was pointed out that in no year since the Association was incorporated in 1916, nor for several years preceding that time, had the income from dues been sufficient to cover the expenses of the Technical Department activities, and that for the seven years 1919 to 1925, with annual dues of $12.00 per annum, the average per capita cost of the Technical Department was $14.65 and the average per capita deficit $2.65.

It was further stated that the increased membership following amendments to the By-Laws, providing for Affiliated memberships at $7.50 per annum, had reduced the per capita cost to $12.17 for the year 1928. The lower average rate of dues, however, had reduced the per capita income to $10.73, resulting in a per capita deficit of $1.44 for the year.

It was pointed out that these deficits had been met annually by


Growth of Membership
of
American Foundrymen's Association
Number of Members
Year
1896 97 98 99 1900 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 1930
200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400

entrance fees, subscriptions, appropriations from exhibit earnings and permit fees. The report contained the recommendation that consideration be given to a slight reclassification of memberships and increased dues in some classes.

In accepting the report, the members present voted unanimously to refer these recommendations to the Board of Directors for their consideration and action. A committee on amendments re membership was appointed, and in the minutes of the annual Board meeting, held Sept. 12, 1929, and published in A. F. A. *Transactions* (1929), vol. 37, page lv, their report appears.

This report, which was unanimously adopted by the Board of Directors, provided for Firm memberships at $25.00 per annum, Individual memberships at $15.00 per annum, Affiliated memberships at $7.50 per annum, and Associate memberships at $5.00 per annum.

The proposed amendments were submitted to the membership for their acceptance or rejection by letter ballot. The result of the ballot is reported in the minutes of the Executive Committee meeting held Nov. 20, 1929, showing a total of only 21 negative ballots.

The ballot provided that changes in dues for members of record should become effective Jan. 1, 1931. It was further provided that all company members of record should have the privilege of electing to continue their memberships at $15.00 per annum by designating some individual in whose name the membership should be carried. The amendments limited Affiliated memberships to persons affiliated with a company holding Firm membership and paying annual dues of $25.00, and Associate memberships to persons actively engaged in educational or research pursuits relating to the foundry industry, not of a commercial character.

At a special meeting of the Board of Directors held Nov. 19, 1930, the Board authorized a letter ballot on amendments to the By-Laws, changing the fiscal year to end June 30th. This amendment was approved to become effective July 1, 1931.

On Dec. 15, 1930, the Board of Directors by unanimous letter ballot instructed the Secretary-Treasurer to waive application of the new rate for dues, previously approved to become effective January 1st, until the beginning of the new fiscal year, July 1, 1931, and to bill all members for the first half of the calendar year at the old rate. All bills for dues were rendered accordingly.

Coupled with the changes in memberships and anticipated increased income from dues, certain new activities were proposed, the major one being a monthly publication. In January, 1930, the first number of *Transactions and Bulletin* was published, continuing the Bulletin and Engineering sections of the previously published *Quarterly Bulletin*, and an added section containing the proceedings of the annual conventions. This has proven an acceptable plan for providing Transactions for all members, but has increased the per capita cost of operating.

To maintain this monthly publication, increase its usefulness to members and support the increasing activities of the Association and its committees for the advancement of the foundry industry, the generous support of firms and individuals is desired.

Nominating Committees

Article IX, Section 1 of the By-Laws reads as follows: "There shall be created annually a Nominating Committee consisting of the last three living past-presidents of the Association and four other members to be elected by the members of the Association at least four months prior to the first day of the annual convention. The manner of their election shall be prescribed by the Board of Directors."

The manner of election prescribed by the Board has been a letter ballot of the members. As a matter of record, the reports of the Nominating Committees for 1930 and 1931 are shown.

On Nov. 3, 1929, the judges appointed to canvass the ballots for the election of four members of the 1930 Nominating Committee reported the election of Melvin J. Evans, Ray J. Doty, Wm. J. Grede and T. H. Addie to serve with Past-Presidents A. B. Root, Jr., S. W. Utley and S. T. Johnston. A meeting of this committee was held in Cleveland, Jan. 30, 1930, at which time officers and directors were nominated in accordance with the provisions of the By-Laws.

Their report was submitted to the entire membership on February 7th and, there being no further nominations, the candidates were all declared elected to the offices for which they were nominated, at the annual meeting of the Association held in Cleveland, May 12, 1930, and assumed office at the annual Board meeting held July 15, 1930.

On Dec. 22, 1930, the judges appointed to canvass the ballot for the election of four members of the 1931 Nominating Committee reported the election of D. G. Anderson, C. S. Neumann, S. B. Cuthbert and S. V. Wood to serve with Past-Presidents S. W. Utley, S. T. Johnston and Fred Erb. The meeting of this committee was held in Birmingham, Ala., on Jan. 20, 1931, at which time officers and directors were nominated in accordance with the provisions of the By-Laws. The report of the Nominating Committee was submitted to the membership under date of Feb. 3, 1931.

Awards

The Board of Awards of the American Foundrymen's Association consists of the last seven living past-presidents of the Association. The Board is self-perpetuating. When each retiring president becomes a member, he takes the place of the senior past-president on said Board. The junior past-president automatically becomes the Chairman of the Board.

1929 Meeting

At a meeting of the Board of Awards held in New York, Nov. 19, 1929, it was unanimously voted to recommend that a John A. Penton Gold Medal of the American Foundrymen's Association be awarded to Harry A. Schwartz, Manager of Research, National Malleable & Steel Castings Co., Cleveland. By letter ballot of the Board of Directors this

award was unanimously approved, and presentation of medal and certificate was made at the annual banquet, May 15, 1930.

1930 Meeting

At a meeting of the Board of Awards held in New York, Nov. 20, 1930, it was unanimously voted to recommend that a J. H. Whiting Gold Medal of the American Foundrymen's Association be awarded to Ralph Stewart MacPherran, Chief Chemist, Allis-Chalmers Mfg. Co., Milwaukee. By letter ballot of the Board of Directors this award was approved, presentation to be made at the 1931 annual convention of the Association.

Auditor's Statement

January 15, 1931.

Mr. N. K. B. Patch, President,
American Foundrymen's Association, Inc.,
Chicago, Illinois.

Dear Sir:

I have examined the books of the American Foundrymen's Association, Incorporated, for the year ending December 31, 1930.

In my opinion the balance sheet for December 31, 1930 (Exhibit A), correctly reflects the condition of the Association as at that date and as shown by the books.

Respectfully submitted,

ROBERT T. PRITCHARD,
Certified Public Accountant.

NOTE: For the purpose of comparison, the auditor's statement shows a balance sheet for the years 1929 and 1930. It will be noted that for the year 1929, when a limited exhibit was held, there was an operating deficit of $5,463.32, and for the year 1930, with a large exhibit, an operating surplus of $11,947.27, an average operating surplus for the two years of $3,241.97.

In considering the total assets as shown in the audit, it will be proper to deduct the principals of the Award Funds, $21,000, as the income only from these funds is available for certain limited purposes.

The Reserve Fund is the total of funds set aside over a period of twelve years, to be available in case of any emergency in the operating of exhibits, a comparatively large activity not financed from dues of members.

Balance Sheet
as at December 31, 1930

ASSETS

	1930	1929
ASSOCIATION ASSETS		
Furniture and Fixtures Less Depreciation Reserve	$ 1,047.89	$ 1,087.04
Cash in Bank	14,052.58	2,414.93
Accounts Receivable	1,036.00	658.00
Supplies on Hand	871.76	1,088.05
Prepaid Rent	.....	500.00
Total Association Assets	$17,008.23	$ 5,748.02
PHILADELPHIA RESEARCH FUND		
Cash in Savings Account	$ 1,969.91	$ 1,912.13
STEEL CASTINGS TEST FUND		
Cash in Savings Account	$ 278.22	$ 270.06
AWARD FUNDS		
Investments (At Cost)	$21,520.10	$21,520.10
Cash in Savings Account	1,739.04	1,639.93
Total Award Fund Assets	$23,259.14	$23,160.03
RESERVE FUND		
Investment (At Cost)	$47,218.59	$46,179.22
Cash in Savings Account	1,703.88	480.54
Total Reserve Fund Assets	$48,922.47	$46,659.76
TOTAL	$91,437.97	$77,750.00

Balance Sheet
(Continued)

LIABILITIES

ASSOCIATION LIABILITIES	1930	1929
Notes Payable	$	$ 3,000.00
Dues Paid in Advance	129.75	3,373.50
Exhibitors' Permits Paid in Advance	1,300.00	3,000.00
Cast Iron Research Fund—Unexpended	928.00	1,837.84
Sand Research Fund—Unexpended	903.21	.....
Steel Surface Research Fund—Unexpended	1,800.00	.....
Total Association Liabilities	$ 5,060.96	$11,211.34
Surplus	11,947.27	*5,463.32
	$17,008.23	$ 5,748.02
PHILADELPHIA RESEARCH FUND		
Balance of Subscription	$ 1,969.91	$ 1,912.13
STEEL CASTINGS TEST FUND		
Unexpended	$ 278.22	$ 270.06
AWARD FUNDS		
Principal of Funds	$21,000.00	$21,000.00
Premiums on Investments	520.10	520.10
Unexpended Income	1,739.04	1,639.93
Total Award Fund Liabilities	$23,259.14	$23,160.03
RESERVE FUND	$48,922.47	$46,659.76
TOTAL	$91,437.97	$77,750.00

*Deficit.

Cash Receipts and Disbursements for Year 1930

CASH IN BANK—January 1, 1930		$ 2,414.93
RECEIPTS		
Dues and Subscriptions	$23,494.68	
Registration Fees	4,660.25	
Exhibitors' Permits	3,200.00	
Exhibitors' Permits in Advance	1,300.00	
Space Rental	81,222.30	
Interest Received	651.33	
Total Receipts		114,528.56
		$116,943.49
DISBURSEMENTS		
Auditing	$ 225.00	
Committee Traveling Expense	3,577.50	
Discount and Exchange	126.11	
Dues of Other Associations	151.00	
Office Expense	680.22	
Postage	1,759.78	
Printing and Stationery	3,576.90	
Publications	15,228.93	
Salaries—Executives	27,622.21	
Stenography and Clerical Salaries	5,554.53	
Taxes	23.18	
Telephone and Telegraph	416.33	
Convention Expenses	2,936.86	
Advertising	4,496.94	
Badges	484.10	
Booth Work	7,629.70	
Building Rental (balance)	6,000.00	
Installation—Labor and Material	2,132.75	
Installation—Superintendent, etc.	2,550.00	
Insurance	816.15	
Janitor Service	629.09	
Manager's and Assistants' Traveling Expenses	1,782.89	
Office Rent	3,000.00	
Power	507.05	
Registration Expense	724.24	
Watchmen and Doormen	1,000.00	
Sand Research	1,671.38	
District Association Expense	408.63	
General Expense	160.17	
Cast Iron Research	2,783.28	
Engineering Foundation for Research	1,000.00	
Note to Harris Trust & Savings Bank	3,000.00	
Furnishings Purchased	235.99	
Total Disbursements		102,890.91
CASH IN BANK—December 31, 1930		$ 14,052.58

Minutes of Executive Committee Meeting 1929-30 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
HOTEL ASTOR, NEW YORK, NOV. 20, 1929

President Fred Erb presiding.

Roll Call

The following Officers and Directors responded to roll call: President Fred Erb, Vice-President N. K. B. Patch, S. W. Utley, S. T. Johnston, B. H. Johnson, and Executive Secretary C. E. Hoyt. Absent, Frank J. Lanahan.

The Executive Secretary reported that at a meeting of the F. E. M. A. the preceding day the members voted in favor of holding the exhibit open two evenings during the Cleveland Convention. This plan was approved by vote of the Executive Committee.

Appropriation for Alloys of Iron Research

The Secretary reported that the Committee on Research Appropriations, consisting of L. W. Olson as Chairman, S. C. Vessy, N. K. B. Patch, W. J. Nugent and E. H. Ballard, had by letter ballot unanimously voted to recommend an appropriation of $1,000 per year for a period of five years, beginning with 1930, for research in alloys of iron under the direction of the Engineering Foundation. On motion the Executive Committee voted to authorize this appropriation.

Sinking Fund Investment

The Secretary reported that there was $3,515 in the Sinking Fund Interest account, drawing 3 per cent. On motion, the Secretary was instructed to purchase bonds for the Sinking Fund of the department of exhibits to the amount of $3,500.

Room Entertainment Report

The Executive Committee voted to authorize the printing of the Executive Secretary's report on Room Entertainment in pamphlet form, to be mailed to all A. F. A. members and exhibitors.

Resolution on Death of H. Cole Estep

The Secretary reported that the Directors had by letter ballot unanimously approved the following resolution drafted in recognition of Director H. Cole Estep, whose death occurred in Cleveland, Sept. 30, 1929:

By Unanimous Action of the
Board of Directors of the
American Foundrymen's Association
This Tribute Is Rendered—

When we so recently gave Cole Estep a resolution of our appreciation, we could not then conceive that Providence would soon deprive us of our friend and loved associate. We stand too near him now to adequately set down in words

our sorrow over his loss. Yet we are filled with an appreciation of his fine, upstanding manhood and of the loyal, unswerving friendliness that was his.

To few men is it given to know that their work is truly recognized. But this one source of comfort is truly ours: Before he went, he knew our love for him and our thanks for all the help he gave us.

In our grief we turn to those he loved to offer them our truest sympathy. May they find some small measure of consolation in the high honor in which his name is held by all who knew him, both in America and overseas.

We wish to record permanently our most sincere appreciation of Harvey Cole Estep as an associate, untiring in his devotion to service, and as a friend—broad-minded, fair and true. The good he did will live long after this resolution is forgotten. However, as a matter of record, we instruct that this tribute be spread upon the minutes, and that a copy in permanent form be presented to his bereaved family.

AMERICAN FOUNDRYMEN'S ASSOCIATION
Fred Erb, President
C. E. Hoyt, Executive Secretary

September 30, 1929,
This day we commemorate.

The committee authorized that this resolution be prepared in permanent form, bound in a folder together with the resolution adopted by the Foundry Equipment Manufacturers' Association and presented to the family of Mr. Estep.

Election of S. C. Vessy to Fill Vacancy

The Secretary announced the unanimous election by letter ballot of the Directors of S. C. Vessy to fill the unexpired term of H. Cole Estep as a Director of A. F. A.

Nominating Committee

The Secretary reported as a matter of record the election of M. J. Evans, R. J. Doty, Wm. J. Grede and T. H. Addie as members of the 1930 Nominating Committee.

Ballot on Revision of By-Laws

The Secretary reported that the tellers appointed by the President to canvass the ballot on revision of the By-Laws had submitted the following report:

Total number of ballots cast	498
Total number of ballots in favor of revision	458
Total number of ballots opposed to revision	21
Split ballots	19

There being no further business, the meeting stood adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of Annual Meeting 1929-30 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
STATLER HOTEL, DETROIT, JULY 15, 1930

President Fred Erb presiding.

Roll Call

The following Officers and Directors responded to roll call: President Fred Erb, Vice-President N. K. B. Patch; Directors E. H. Ballard, H. Y. Carson, A. E. Hageboeck, C. E. Hoyt, B. H. Johnson, S. T. Johnston, P. J. Krentz, Frank J. Lanahan, Arnold Lenz, L. W. Olson, S. W. Utley, S. C. Vessy and D. H. Wray.

Others present were Directors-elect R. M. Maull and D. M. Scott, Technical Secretary R. E. Kennedy, and past president B. D. Fuller.

Reports of Officers

The reports of the Executive Secretary, Treasurer, Technical Secretary and Manager of Exhibits were read and accepted.

It was moved that the report of the Technical Secretary on general committee activities and of the Chairman of the Divisional Activities Correlation Committee be passed over and presented at the meeting of the new Board.

Room Entertainment

In a special report the Executive Secretary reviewed the resolutions adopted and efforts made to reduce room entertainment at annual conventions. The report included letters from the managers of all but one of the principal hotels of Cleveland.

It was the consensus of opinion that the action of the Board and others had resulted in a decided improvement and that the policy should be continued.

Report of Finance Committee

The Finance Committee reported that they had examined the last audit of the books of the Association for the year ending Dec. 31, 1929, and the Treasurer's itemized statement of income and expense from the date of the last audit to July 1st. The report concluded with the recommendation that the Executive Secretary and Manager of Exhibits be given a bonus of 3 cents per square foot based on the amount of space sold for commercial exhibits at the Cleveland Convention.

On motion of the Chairman, duly seconded, the report of the committee was accepted and the bonus authorized.

Report of the Executive Committee

It was moved that the minutes of the Executive Committee meeting held in New York, Nov. 20, 1929, be approved and included in the records of this Board. Motion seconded and carried.

These minutes reported the death on Sept. 30, 1929, of Director H.

Cole Estep, and the Chair asked all present to stand in silent tribute of Mr. Estep.

Board of Awards Action

The Secretary reported that it should be made a matter of record that by letter ballot the Directors had approved the recommendation by the Board of Awards that the John A. Penton Medal and award be made to Harry Adolph Schwartz at the 1930 convention in recognition of his contributions to the advancement of the malleable casting industry.

Castings Promotion

On motion, it was voted to drop the Committee on Castings Promotion, created in 1928, and recommend to the incoming Board inaugurating other plans for carrying out the purposes of the committee.

Report of Election of Officers

The Secretary reported that at the annual meeting of the Association held in Cleveland, May 12, the following officers were declared elected to assume office following adjournment of the annual meeting of the present Board:

For President, to serve one year:

N. K. B. Patch, Secretary, Lumen Bearing Co., Buffalo.

For Vice-President, to serve one year:

E. H. Ballard, General Foundry & Pattern Shop Superintendent, General Electric Co., West Lynn, Mass.

For Directors, each to serve three years:

C. S. Anderson, Vice-President & General Manager, Belle City Malleable Iron Co., Racine, Wis.
H. K. Culling, Vice-President, Carondelet Foundry Co., St. Louis, Mo.
Fred Erb, President, Erb-Joyce Foundry Co., Detroit.
R. M. Maull, Treasurer, Tabor Mfg. Co., Philadelphia.
D. M. Scott, Vice-President, Gould Coupler Co., Depew, N. Y., and The Symington Co., Rochester, N. Y.

Appreciation

After expressing his appreciation to all directors for their cooperation and helpfulness during his term of office, President Erb declared the meeting of the old Board adjourned and turned the gavel over to the incoming President, N. K. B. Patch.

Mr. Johnston moved and Mr. Lanahan seconded the motion that a vote of thanks be extended to Mr. Erb for the pleasant and efficient way in which he had conducted our meetings and the grace and dignity with which he had conducted the affairs of the Association, and that the Board recommend his election to Honorary Membership in the American Foundrymen's Association. Motion carried unanimously.

Respectfully submitted,

C. E. HOYT, *Executive Secretary*,
FRED ERB, *President*.

Minutes of First Meeting 1930-31 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
STATLER HOTEL, DETROIT, JULY 15, 1930

President N. K. B. Patch presiding.

President Patch, in assuming the Chair, said "Gentlemen: In assuming this office I wish to assure you that it is not without some misgiving. Looking back over the history of the Association and the men who have held this office, one cannot help but be struck with wonder at the fine personality represented by the different presidents of the A. F. A. That, I believe, is a challenge to the man who succeeds them, and I shall meet that challenge with all that is in me and with your help and cooperation."

Roll Call

The following Officers and Directors responded to roll call: President N. K. B. Patch, Vice-President E. H. Ballard, and Directors Fred Erb, C. E. Hoyt, B. H. Johnson, S. T. Johnston, P. J. Krentz, Frank J. Lanahan, Arnold Lenz, R. M. Maull, L. W. Olson, D. M. Scott, S. W. Utley and D. H. Wray.

Others present were past Directors H. Y. Carson, A. E. Hageboeck and S. C. Vessy, Technical Secretary R. E. Kennedy, and Past-President B. D. Fuller.

Organization of New Board

The Chair announced that the By-Laws provided for the election by the Board of an Executive Secretary, a Treasurer, a Technical Secretary, an Assistant Secretary, and a Manager of Exhibits. The By-Laws also provide that the Board shall elect four of their members who, together with the President, Vice-President and Executive Secretary, shall constitute an Executive Committee.

Appointment of Nominating Committee

The Chair appointed Directors P. J. Krentz, E. H. Ballard and S. T. Johnston as a committee to nominate officers and members of the Executive Committee, and stated that there would be a short intermission while the Nominating Committee retired to prepare their report.

Report of Nominating Committee

The committee appointed to nominate officers of the Association and members of the Executive Committee, in accordance with the provisions of the By-Laws, reported as follows:

> 1—The committee recommends that the offices of Executive Secretary, Treasurer and Manager of Exhibits be combined, in accordance with the provisions of Article 3, Section 1 of the By-Laws.

On motion duly seconded the recommendation was approved.

2—For the combined offices of Executive Secretary, Treasurer and Manager of Exhibits, the committee nominates C. E. Hoyt.

3—For the office of Technical Secretary the committee nominates R. E. Kennedy.

4—For the office of Assistant Secretary-Treasurer the committee nominates Miss Jennie Reininga.

5—As members of the Executive Committee to serve with the President, Vice-President and Secretary, the committee nominates Directors Fred Erb, Harold S. Falk, B. H. Johnson and S. W. Utley.

The Chair called for further nominations. There being none, it was moved that the nominations be closed and that the report of the committee be adopted. Motion carried.

Finance Committee

On motion the President, the Vice-President and the immediate Past-President were named as the Finance Committee for the ensuing year.

Disbursement of Funds Resolutions

The following resolutions were read and unanimously approved by vote of the Directors:

Resolved, that checks for the withdrawal of funds deposited in the name of the Association shall bear two signatures, as follows:

the President and the Executive Secretary-Treasurer,
the Vice-President and the Secretary-Treasurer, or
the President and the Vice-President.

Be It Further Resolved, that the resolutions required by the banks in which the funds of the Association are deposited, authorizing the withdrawal of funds, are hereby approved and adopted, and the Executive Secretary authorized to certify thereto.

Be It Further Resolved, that the Officers of the Association are hereby authorized to open an account in the convention city for a special convention checking fund, they to determine how this account shall be opened and the signatures required for the withdrawal of said fund.

Be It Further Resolved, that the Board authorize a Secretary-Manager's petty cash fund of $1,000, said fund to be reconciled at the end of each month by a full statement of expenditures.

Be It Further Resolved, that the President and Executive Secretary are authorized to employ such assistance as is deemed necessary to take care of Association activities, compensation for such services to be approved by the Finance Committee.

Treasurer's and Assistant's Bond

By vote of the Directors, the Treasurer and Assistant Treasurer were each required to give a bond to the amount of $5,000, the premium on said bonds to be paid by the Association.

International Relations Committee Report

The Chair called on Dan M. Avey, Chairman of the Committee on International Relations, who reported on a meeting of the committee held

during the convention and on negotiations conducted by our European Representative, Mr. Delport, re proposed change in schedule of international congresses that would provide for more frequent congresses being held in the United States. It was pointed out that the present schedule provides for the next congress in the United States in 1938. The discussion brought out the possibility of an earlier meeting and on motion the question was referred to the Executive Committee.

At this point the meeting adjourned for luncheon.

AFTERNOON SESSION

Technical Secretary's Report

The Chair announced that the next order of business would be consideration of the report of the Technical Secretary, presented at the morning meeting and referred to the new Board. General discussion followed the presentation of each subject, which was helpful to those in charge of Association activities.

Foundry Equipment Standards

On motion the Board approved the formation of a standing committee under A. S. A. procedure and under the joint sponsorship of the A. F. A. and the A. S. M. E., to which would be referred all requests for standard activities dealing with foundry equipment and supplies, of a nature not in the field of the A. S. T. M.

Mechanical Standards Advisory Council

The Board voted to approve A. F. A. representation on the recently formed Mechanical Standards Advisory Council, on which 22 national associations are represented.

Foundry Education in Engineering Schools

The Secretary read a report of the special committee appointed to consider the advancement of foundry education in cooperation with engineering schools. The Secretary stated that the report had been approved at a members' session and referred to the Board of Directors. Following discussion, the Board voted to sponsor the organizing of a joint committee to study foundry education in cooperation with engineering schools.

Research Appropriations

The following report was submitted on proposed research activities:

(a) *Sand Research.* The Committee on Molding Sand Research requests an appropriation to defray the cost of carrying on the committee's work during the coming year.

(b) *Liquid Shrinkage.* Both the A. F. A. Advisory Committee and the Gray Iron Division recommend that an appropriation be made for continuing an investigation to determine methods for testing liquid shrinkage, with attention being given to gray iron and malleable cast iron.

(c) *Nonferrous Test Bars and Liquid Shrinkage.* The Nonferrous Division requests an appropriation of sufficient funds to establish a Re-

search Fellow at the Bureau of Standards to investigate test bars and liquid shrinkage of nonferrous metals.

(d) *Factors Affecting the Surface of Steel Castings.* The Steel Foundry Division requests an appropriation sufficient to support a year's investigation of factors affecting the surface of steel castings.

(e) *Alloys of Iron Research.* It was announced that the Executive Committee of the Board, on recommendation of the Research Appropriations Committee, had authorized the appropriation of $5,000, to be paid in $1,000 annual installments to the Engineering Foundation, to aid in the alloys of iron research.

Following discussion it was voted to refer all research proposals to a Committee on Research Appropriations to be appointed by the President, with instructions to draw up some general policy for all research and submit their recommendations to the Executive Committee.

Report of Finance Committee

The Finance Committee, consisting of Vice-President E. H. Ballard as Chairman, President N. K. B. Patch and Past-President Fred Erb, submitted the following report on salaries:

The Finance Committee recommends that there be no change in the salaries of officers and assistants for the balance of the fiscal year ending Dec. 31, 1930.

The Committee further recommends that beginning Jan. 1, 1931, and until further authorization the salary of the Executive Secretary-Treasurer shall be $6,600.00 per annum, the salary of the Technical Secretary $6,600,the salary of the Manager of Exhibits $8,400.00 per annum, and the salary of the Assistant Secretary-Treasurer $3,600.00 per annum.

Mr. Lanahan moved the adoption of the committee's report, which was seconded by Mr. Olson and carried.

Resolution Authorizing Payment of Committee Meeting Expenses

On motion duly seconded, the following resolution was adopted:

Resolved, that the Treasurer be authorized to reimburse the traveling expenses of directors and committee members for attendance at any regularly called Board or committee meetings, with the following exceptions:

When meetings are held in conjunction with meetings of other committees or associations, the Treasurer is authorized to determine what proportion of the expenses of attending such meetings shall be paid by the A. F. A.

No expenses will be paid to directors or committee members for attendance at meetings held during the week of the annual convention of the Association, unless specially authorized.

Committee Appointments

On motion, the following resolution was adopted:

Resolved, that the President be authorized to make all appointments for standing and special committees that are not provided for in the By-Laws or by special act of the Board.

Appropriations for Prizes

It was voted to authorize the offering of prizes for apprentice molding and pattern making contests at the 1931 convention of the same

value as offered in 1930, provided the Board of Awards votes the necessary funds for such prizes.

Convention City

The Executive Secretary announced the invitations received for holding the 1931 convention of the Association and on motion all invitations were referred to a special convention city committee to be appointed by the President, they to make their recommendations to the Executive Committee, who were given authority to decide the time and place of the 1931 annual meeting.

1931 Nominating Committee

The Chair appointed a committee of three to select names of members for the Nominating Committee ballot. S. W. Utley, Chairman, submitted the following report:

The committee appointed to recommend members whose names shall appear on the ballot for the election of four members and four alternate members of the Nominating Committee for 1931 submit the following:
M. W. Pohlmann, Vice-Pres., J. W. Pohlmann Foundry Co., Buffalo.
D. G. Anderson, Development Engr., Western Electric Co., Chicago.
C. S. Neumann, Pres., Union Mfg. Co., New Britain, Conn.
J. D. Stoddard, Vice-Pres., Detroit Testing Laboratory, Detroit.
W. H. Mantz, Gen. Mgr., Atlas Foundry Co., Irvington, N. J.
J. B. Greenstreet, Gen. Supt., Olney Foundry Co., Philadelphia.
S. B. Cuthbert, Supt. of Fdrs., Carnegie Steel Co., Braddock, Pa.
H. Bornstein, Director of Laboratories, Deere & Co., Moline, Ill.
C. J. Scullin, Alda Research Laboratories, St. Louis.
S. V. Wood, Pres., Minneapolis Electric Steel Castings Co., Minneapolis.

On motion, the report of the committee was approved and the Secretary instructed to have the ballot printed and mailed to all members, after first securing the consent of the members nominated.

Election of H. A. Schwartz to Life Membership

On motion, Harry Adolph Schwartz, 1930 A. F. A. gold medallist, was elected to Life Membership in the American Foundrymen's Association.

The Board approved of the recommendation that the Board of Awards provide, in making their recommendations to the Board of Directors for the election of a medallist, that the recommendation carry with it the election to Life Membership, a certificate of Life Membership to be presented with the medal.

Castings Promotion

On motion, the Directors voted to refer the question of the employment of someone to carry out the program for which the Committee on Castings Promotion was organized, which committee it was voted at the morning meeting to discontinue, to the Executive Committee.

Resignation of L. W. Olson

Director Louis Olson, who had served the Association as a Director, Vice-President, President and again as a Director since 1920, stated that

he desired to resign so as to give an opportunity to some one else to serve. On motion the resignation was accepted with regret and expressions of sincere appreciation for the service he had rendered the Association.

Fred L. Wolf Elected a Director

The Board proceeded, under provisions of the By-Laws, to elect Fred L. Wolf, Technical Superintendent of the Ohio Brass Co., as Director to fill the unexpired term of Mr. Olson, resigned.

Appreciation

Directors S. C. Vessy, A. E. Hageboeck and H. Y. Carson, whose terms of office had expired, expressed their pleasure at having served as Directors and were given a vote of appreciation for services rendered.

On motion, all matters requiring action, but not definitely determined at this meeting, were referred to the Executive Committee with power to act, whereupon the Chair declared the meeting adjourned to meet again at the call of the President.

Respectfully submitted,

C. E. HOYT, *Executive Secretary,*
N. K. B. PATCH, *President.*

Minutes of Special Meeting 1930-31 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
HOTEL ASTOR, NEW YORK, NOV. 19, 1930

President N. K. B. Patch presiding.

Roll Call

The following Officers and Directors responded to roll call: President N. K. B. Patch, Vice-President E. H. Ballard, Executive Secretary C. E. Hoyt, and Directors Fred Erb, B. H. Johnson, S. T. Johnston, Frank J. Lanahan, R. M. Maull, S. W. Utley and F. L. Wolf.

Death of Dr. Richard Moldenke

President Patch, in calling the meeting to order, announced the death on Monday, Nov. 17, of Dr. Richard Moldenke, Honorary Member and Secretary-Treasurer of the American Foundrymen's Association from 1900 to 1914. President Patch then requested the Directors present to stand with him in silent tribute to the memory of this valued member of the American Foundrymen's Association and the foundry industry.

Following this tribute, the appointment of a committee to prepare a suitable memorial to be entered upon the records of the Association, and an engrossed copy to be presented to the family, was duly authorized. A suitable floral tribute was also authorized and provision made for official representation at the services to be held in Plainfield, N. J., on Thursday, November 20th.

Amendments to By-Laws

It was moved by Mr. Utley and seconded by Mr. Johnston that the Board authorize and instruct the Executive Secretary to submit to the members for approval by letter ballot the following:

"I cast my ballot {for / against} changing the fiscal year of the Association to begin July 1st and end June 30th, to take effect July 1, 1931, and making the necessary changes in the wording of the By-Laws to comply with this change in dates."

"I cast my ballot {for / against} adding to Article VIII of the By-Laws a paragraph to be worded so as to comply with postal laws and regulations governing second-class mail matter, requiring that a portion of each member's annual dues be applied as subscription to the Association's monthly publication, *Transactions and Bulletin*."

In the event of the change in fiscal year being approved by ballot of the members, the Executive Secretary was authorized to bill all members on January 1st for six months' dues, or to June 30th, and on July 1st bill all members for one year's dues from that date.

Subscription Price of "Transactions and Bulletin"

It was moved by Mr. Ballard and seconded by Mr. Utley that the subscription price of the *Transactions and Bulletin* be $5.00 for the period of the present fiscal year.

On motion by Mr. Lanahan, duly seconded, the meeting stood adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of Executive Committee Meeting 1930-31 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
HOTEL ASTOR, NEW YORK, NOV. 19, 1930

President N. K. B. Patch presiding.

Roll Call

The following Officers and Directors responded to roll call: N. K. B. Patch, E. H. Ballard, Fred Erb, B. H. Johnson, S. W. Utley and C. E. Hoyt.

President Patch, in the Chair, announced that the first order of business would be receiving the report of the Committee on Research Appropriations, and called for the reading of this report by Secretary Hoyt. The report follows:

"Members of the Executive Committee,
American Foundrymen's Association.
Gentlemen:

"The Committee on Research Appropriations met in Buffalo on October 17th to consider formal requests that had been made for research appropriations and to examine the data in connection with these researches that had been prepared by Secretaries Hoyt and Kennedy, and now submit the following report:

"The Committee feels that with the growing applications for appropriations for work of this nature, very careful attention will have to be given to the basic principles underlying this question. We believe that primarily the function of the American Foundrymen's Association is to make available to our membership the results of such research as has been made by those who are willing to give such information to the industry, rather than actively to conduct research ourselves. Modern research is a very expensive proposition. To be of practical benefit, it must be very carefully directed to certain definite problems, and not to generalities. Our Association is not so organized as to finance the handling of research problems of any magnitude.

"With these thoughts in view, the Committee feels that it is perhaps justified in stimulating the starting of certain researches, but with the distinct understanding that it cannot proceed very far along these lines because of financial limitations.

"In considering such researches, it believes that these can be divided into two classes: First, those that directly affect all branches of the foundry industry, such as the research into molding sands and core sands; and second, those which affect only a single branch, such as the research covering the liquid shrinkage of cast iron, and that into the factors affecting the surface of steel castings. Research problems of the latter nature are obviously of very little interest to those not engaged in the branch of the foundry industry to which they refer, and your Committee believes that the branches affected should bear the major part of the expense to be incurred.

"Your Committee further recommends that before actual work is started on any research or investigation of such a nature, the Committee having it in charge should make a careful survey of the industry to find out what is being done by the various plants to investigate or to solve the particular problem in mind, and to start the work only after the results of this search have been carefully analyzed. We are not referring now to the printed matter, such as is usually collected in a bibliography, but rather to the current work or investigation which may be carried on at the present time by various foundries in various parts of the country.

"With these thoughts in mind, your Committee recommends the following research appropriations, for the balance of the present Association year, that is, until the Annual Meeting of the Board of Directors:

"(1) For continuing the work of the Molding Sand Committee, $1,500.00.

"(2) Gray Iron Research, for continuing work on liquid shrinkage at the Bureau of Standards, $1,873.44.

"This appropriation is to carry until May 31, 1931, at which time it is expected and planned that the work will be completed and the appropriations discontinued.

"(3) In view of the well-thought-out and carefully planned program of the Steel Committee, covering research on factors affecting the surface of steel castings, for which an appropriation of $5,000.00 was asked, your Committee recommends an appropriation from the Association Treasury of $1,800.00, the Steel Foundry Committee to be responsible for raising the balance of the required money by subscriptions from steel foundries.

"(4) In response to the request for an appropriation of $3,000.00 to initiate and carry on research on test bars and liquid shrinkage in high-shrinkage alloys for nonferrous castings, this work supplementing the work of the Nonferrous Ingot Metals Institute and the A. I. M. E., the Committee recommends that the American Foundrymen's Association appropriate 40 per cent of the money required. This means that the nonferrous foundries will raise such sum as may be necessary, on the basis that for each $6.00 raised by them the Association will add $4.00 from its Treasury, up to, but not exceeding, an amount of $2,000.00, from Association funds.

Respectfully submitted,

S. W. UTLEY, *Chairman*,
E. H. BALLARD,
B. H. JOHNSON,
N. K. B. PATCH, *ex-officio*."

Following discussion, it was moved that the report as a whole be accepted and the appropriation of Association funds, in accordance with the recommendations of the committee, authorized. Motion carried.

Report of Special Committee on Selection of Convention City

The report of the special committee appointed to name the time and place of the 1931 convention was received and on motion it was voted to make this report, with its recommendation for 1932 place of meeting, a matter of official record.

Rules and Regulations Governing 1931 Exhibit

On motion duly seconded, the Executive Committee voted to approve and make effective the Rules and Regulations for governing the 1931 exhibit the same as those which governed the 1929 exhibit at the Stevens Hotel, with the following exceptions:

Hours of Exhibit

The official opening hour of the exhibit will be 12:00 o'clock noon, Monday, May 4th. The opening hour on Tuesday, Wednesday and Thursday will be 8:30 a. m. and the closing hour each day 6:00 p. m.

Price of Space

On motion duly seconded it was voted that the price of space should

range from $1.00 to $1.25 per square foot plus corner premiums, the maximum rate to apply to preferred locations where the maximum of service is provided.

Limitations

On motion duly seconded the amount of space to be allotted to any one exhibit, character of exhibits, and the extent of operations were to be determined by the Manager of Exhibits, who would be governed by the general policies adopted for the 1929 exhibit.

Dinners

The committee recommended that the annual Exhibitors' Dinner be held on Monday evening, May 4th, and the annual Banquet on Wednesday evening, May 6th.

Engineering School Exhibits

No definite action was taken but it was the consensus of opinion that the plan of having engineering school exhibits, inaugurated at the Cleveland Exhibit, should be continued, with limitations corresponding to those imposed on commercial exhibits, provided this could be done to the mutual satisfaction of the schools and the Association.

Ladies' Entertainment

It was voted to appropriate funds not to exceed $750.00 from the registration fees for defraying the cost of ladies' entertainment.

Salaries

Acting upon the recommendation of the Finance Committee, the Executive Committee voted an increase in salary of $50.00 per month for Wm. W. Maloney, Assistant Managing Editor, effective Nov. 1, 1930.

Birmingham Regional Meeting

It was announced that this meeting would be held on Jan. 20 and 21, 1931, and that it would be known as the Southern Regional Meeting of the American Foundrymen's Association with the Birmingham District Foundrymen and Allied Industries Cooperating.

Proposed Foundry Exhibit in Museums of the Peaceful Arts

Vice-President Ballard reported that on the day previous he, together with Secretary Hoyt and Dan M. Avey, had visited the Museums of the Peaceful Arts as the guest of Mr. Joseph W. Roe, Consulting Engineer, and discussed with him plans for a foundry exhibit at the Museums. Mr. Ballard stated that Mr. Roe would prepare an outline of this proposed exhibit and forward copies to the offices of the A. F. A., and would then request that a committee of the A. F. A. be appointed to cooperate and advise with the authorities of the Museums in the preparation of this exhibit.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of Special Meeting of the Committee on Convention City

AMERICAN FOUNDRYMEN'S ASSOCIATION
HOTEL STATLER, BUFFALO, OCT. 17, 1930

Chairman N. K. B. Patch presiding.

Roll Call

The following members of the Special Committee on Convention City responded to roll call:

N. K. B. Patch, Lumen Bearing Co., Buffalo, Chairman.
E. H. Ballard, General Electric Co., West Lynn, Mass., Vice-President A. F. A.
L. L. Anthes, Anthes Foundry, Ltd., Toronto, Canada.
B. H. Johnson, R. D. Wood & Co., Philadelphia.
Frank J. Lanahan, Fort Pitt Malleable Iron Co., Pittsburgh.
Henry W. Standart, Northern Engineering Works, Detroit.
S. W. Utley, Detroit Steel Casting Co., Detroit.
S. C. Vessy, W. W. Sly Mfg. Co., Cleveland.
C. E. Hoyt, Executive Secretary, A. F. A., member *ex-officio*.

The Chairman announced that the A. F. A. had authorized the Committee on International Relations to extend an invitation to the International Committee of Foundry Associations to hold an International Foundry Congress in America in 1934. He stated further that the committee in its deliberations should consider possible places of holding the International Foundry Congress in 1934 and consider a tentative program for holding the intervening conventions of A. F. A. The Chairman further announced that, following the policy established in 1929, a limited exhibit would be held in conjunction with the 1931 annual convention.

Invitations from various cities were considered, supported by information as to facilities and accommodations available in each city. The committee were unanimous in feeling that it was essential to the success of conventions with limited exhibits that all activities of convention week be housed in one building.

Following discussion, the committee were unanimously of the opinion that the accommodations offered at the Stevens Hotel, Chicago, were superior to the accommodations offered in other cities and voted to hold the next convention at the Stevens Hotel the week of May 4, 1931.

Coupled with this decision was the recommendation that the 1932 convention be held in Philadelphia and that an option be secured on the new Philadelphia Convention Hall for a convention and large exhibit of the Association the first full week in May, 1932.

It was a further recommendation of the committee that, in the future, all annual meetings of the Association be scheduled for the first full week in May.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Necrology

Harvey Cole Estep

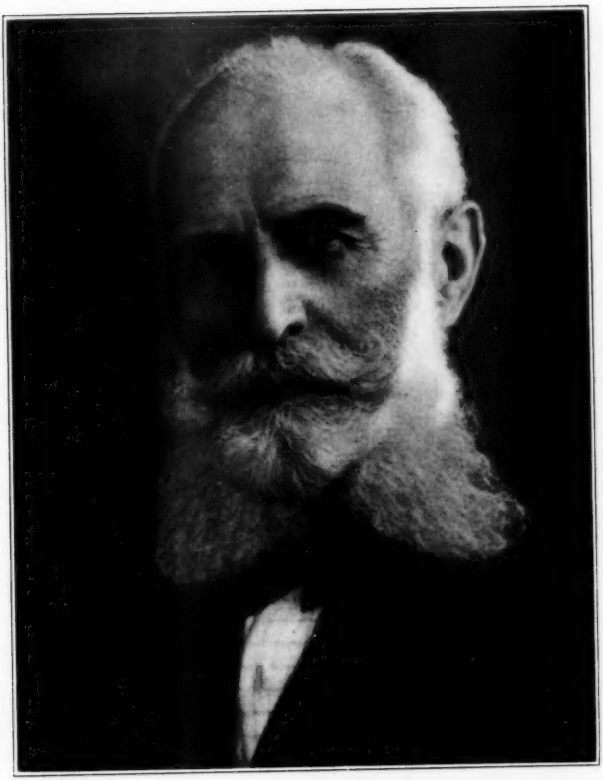
September 30, 1929, Director Harvey Cole Estep died at Cleveland, Ohio. A record of official action taken and copy of resolution adopted is reported in the minutes of the Executive Committee meeting of November 20, 1929.

Dr. Richard Moldenke

November 17, 1930, Dr. Richard Moldenke, Secretary-Treasurer 1900-1914, a Medallist and Honorary Member of A. F. A., died at Watchung, New Jersey. A tribute to his life and work is given in the **Transactions and Bulletin** for December, 1930.

Alfred E. Howell

January 25, 1931, Alfred E. Howell, President of the A. F. A. in 1914, died at Nashville, Tennessee. He served continuously as an Officer and Director from 1909 to 1926. A tribute to his life and work is given in the **Transactions and Bulletin** for February, 1931.



Nov. 1, 1864

Dr. Richard Moldenke

Nov. 17, 1930

Some Features of the Pulverized-Coal-Fired Air Furnace

By E. F. Wilson,* Lockport, N. Y.

Abstract

This paper deals with the practical and theoretical factors of the construction and operation of the air furnace for producing malleable castings. The main headings of discussion are: (1) Design, (2) Materials of Construction, (3) Methods of Furnace Construction, (4) Calculation of Mixtures, (5) Features Affecting Oxidation, (6) Furnace Operation, (7) Test Methods to Determine Heat Progress, (8) Doping the Melt, (9) Pouring the Melt, (10) Features of Combustion, (11) Powdered Coal Combustion, (12) Fuels, (13) Bath Reactions and (14) Modification of Air Furnaces. Each of these features is discussed in considerable detail, the author giving the practice of his organization. It is stated that the air furnace has a much larger field in the melting of iron than at present is utilized. In relation to design, the reasons for the various details are given, covering the length, width, side walls, combustion chamber, hearth bottom, roof, bridge walls and tapping spouts. The standard refractory shapes are listed and the effect of severity of service brought out. Tests of refractories also are given. Under calculation of the mixtures, the reasons for using the various materials are given. Slags and atmospheres are discussed as factors affecting oxidation. Theories of combustion and heat transfer in the melting process are reviewed. Under determination of heat progress, methods for testing the temperatures and fluidity are compared, the methods discussed being the cup test, fluidity test, steel rod test, use of optical pyrometer and the test for degree of graphitization. Mechanical features of pouring the melt are listed while the metallurgical considerations of combustion for the various fuels are compared and bath reactions discussed.

*Metallurgical Engineer, Jefferson Union Co.

INTRODUCTION

1. The air furnace, which is used chiefly in the United States in the manufacture of malleable cast iron, has not been treated in modern technical literature to its warranted extent. The writer, with no pretensions to any nearly complete knowledge of all phases of the furnace and its operations, is thereby encouraged to deal with some main characteristics in order to promote additional thought and discussion relative to the subject.

Economic Field for the Air Furnace

2. The economic field for the air furnace today lies chiefly in the production of black heart malleable iron. It is adaptable, however, for gray cast iron of superior quality, and the growing interest in high-test cast iron and, in general, irons of greater strength than hitherto considered, offers future possibilities for this type of furnace.

3. The use of alloy cast irons would appear most rational only if the original matrix is developed to its highest physical properties, which the writer feels is readily attainable with the advantages of such a furnace.

4. The modern cupola is representative of high economic efficiency, both as a thermal agent and in mobility for producing metal on a widely varying schedule. The air furnace does not attempt to compete with this, as the product is so unlike in quality that comparableness can be based only on the requirements of consumers. The following are superiorities that the air furnace possesses as a metallurgical device:

Advantages of Air Furnace

(1) Product can be produced of lower carbon limits or, in general, to various analyses of greater range and exactness.

(2) No marked pickup of sulphur or absorption of impurities from the fuel used need occur.

(3) The product is uniformly consistent in properties, rather than varying from pour to pour.

(4) Higher temperatures may be attained more easily with consequent greater fluidity for pouring intricate castings.

(5) Secondary or, in fact, primary graphitization may be controlled by modifying thermal treatment of the iron in the molten state.

(6) Irons of minimum non-metallic inclusions may be obtained.

(7) Alloys may be added freely to the best advantage.

(8) Better melting stock may be used with the knowledge that it will not be impaired but generally improved by the melting operation.

(9) Better physical properties of the metal all around, and consistently so.

(10) Probably more favorable to off-iron or pig that has been improperly smelted.

5. As the limitations of the air furnace, in comparison with the cupola, are essentially economic, no details will be considered.

Foundry Scrap Causes

6. To take advantage of the favorable features of the furnace, proper and able operation is required. In any foundry the main scrap losses may be divided into those due to molding sand, gating, the mechanics of mold making and the condition of the molten iron as delivered for pouring. The first feature is perhaps the most serious, but it is believed that losses by sand also are affected by pouring circumstances as well as by methods of gating.

7. Experience has taught that the following are dependent on the metal condition at the time of pour either as a function of temperature or analysis:

(1) Tendency to form blowholes.

(2) Shrinkage, as voids showing dendritic formations or separations so small as not to be readily visible but determinable as porosity by an air-pressure test.

(3) Broken-in gates.

(4) Contributions to surface blows, sponginess and like features, known as sand holes.

(5) Misruns.

(6) Core cuts.

(7) Primary graphitization.

(8) Variation of casting dimensions from standard.

(9) Hot cracks due to large differences in cross-section.

(10) Burnt-on sand.

(11) Formations of inverse segregation.

8. As the above are matters deserving a separate treatment, no discussion of them will be accorded here.

9. This paper aims to offer some practices developed in the

foundry division of the Jefferson Union Co. according to the author's point of view. No brief is held for any superiority of methods which are subject to local modifications.

AIR FURNACE DESIGN

10. The features concerned in the design of an air furnace should result in maximum fuel economy commensurate with the desired melting speed. These also should allow for necessary conveniences as to pouring, charging and flexible adjustments to meet average contingencies. The difficulties in meeting the optimum of all these result in an effective design adapted to the best possibilities of each installation.

11. For the purpose of illustration, a 15-ton air furnace, operating on two heats each day, is shown in accompanying sketches (Fig. 1, 2, 3). Further description given below is chiefly with this furnace in mind as fairly typical of an installation of current practice. The logic of the various dimensions will be briefly considered.

Length

12. The length of the air-furnace hearth is mainly empirical and is dependent on the effective flame intensity at the point of the bath farthest from the burner mouths. The length shown herewith has been accepted as good practice under the prevailing conditions. Less than this value would result in decreased economy, due to the smaller area for heat absorption.

13. While the writer has lacked adequate facilities for a practical determination, he is content to accept the general experience that a greater hearth length would result in no marked economy, either thermally or in furnace maintenance.

Width

14. The furnace width has a quite definite limitation in the nature of the roof construction and ability to skim the iron. The roof consists of a series of bungs along the furnace length, made tight at the breaks by being plastered with fire clay on the outside.

15. The bung consists of an arch of special firebrick, carried in a cast-iron frame with the arch ends supported by a plate hinged to this frame. Two heavy bolt arms fix each plate and exert the leverage required to carry the included bricks.

16. This applied load, plus additional strains set up from

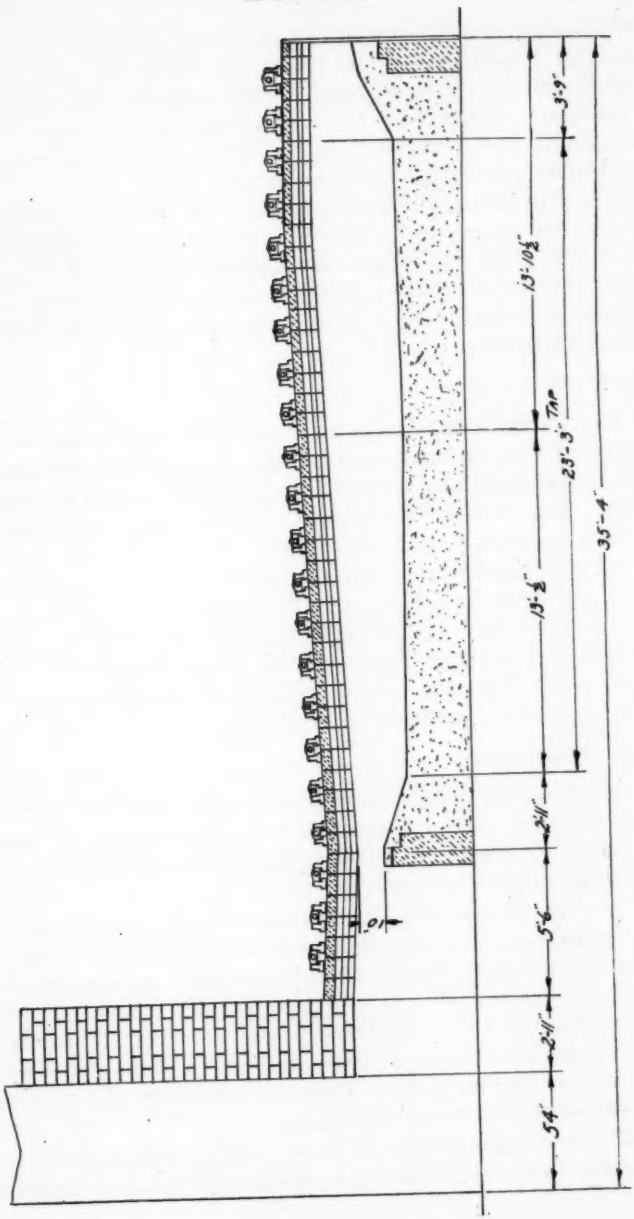


FIG. 1—LONGITUDINAL SECTION OF PULVERIZED-COAL-FIRED AIR FURNACE OF 15-TON CAPACITY.

thermal expansion of the bricks in service, is limited by the compressive resistance of the refractory. Thus the span is defined by the vertical component of the arch retaining the brick in position. A relatively flat arch is desirable for even flame distribution across the section and to reflect and radiate the heat to the bath instead of to the furnace walls.

17. The furnace hearth width of 6 ft., which is our practice, implies an arch span of 7 ft. 6 in., with a 9 in. spring. An 8-ft. width of hearth is not uncommon. In furnaces of older design the width was sometimes tapered at the bridge wall, probably to concentrate the hot gases over a narrower bath at this colder section.

Side Walls

18. Carrying the bungs are 13-in. side walls composed of a layer of 9-in. straights laid parallel to cast-iron side plates with an adjacent inner row of straights laid normal in length to this. This offers a 9-in. length to oppose erosion and solution and still maintain a rigid brickwork.

19. No insulation is employed as the service is especially severe and whatever cooling normally occurs, serves to decrease penetration of any fluxing materials. In fact, the brickwork is occasionally carried above the side plates to accelerate this cooling effect. The side plates are held by tee-shaped supports carried into the foundation.

Combustion Chamber

20. The height of the combustion chamber may be measured along the side walls for convenience. This feature is again determined by experience and may show more or less variation according to individual preferences.

21. The minimum is fixed by the volume occupied by the stock at any part. If the stock material is light and bulky, it may very nearly approach the roof, the heat transfer accomplished by penetration of the hot gases through the mass as well as passage over the top. More densely piled stock requires greater consideration for the passageway of the flame; otherwise local, intense heating is liable to occur with fusion of the metal, to freeze again at a lower level.

22. This agglomerates the mass, making it more resistant to further heat conduction and subsequent fusion. Excessive

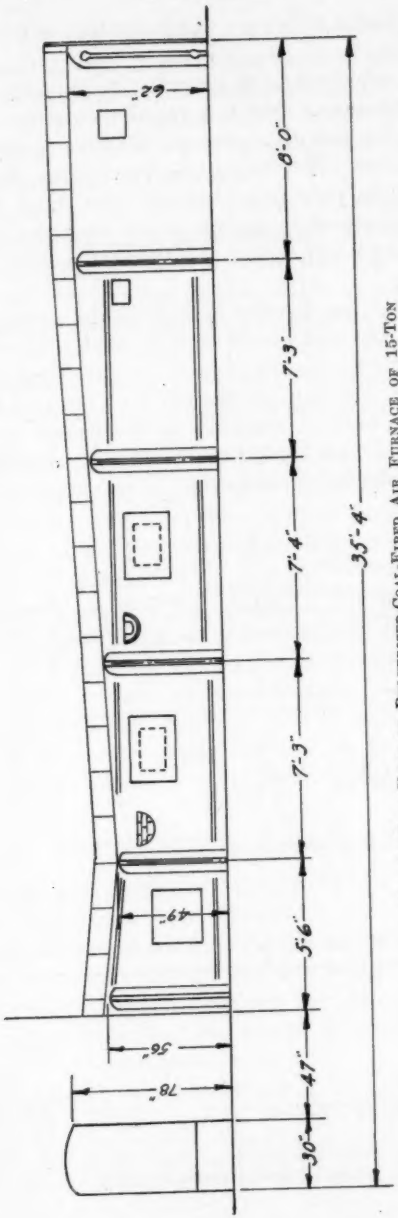


FIG. 2—SIDE VIEW OF PULVERIZED-COAL-FIRED AIR FURNACE OF 15-TON CAPACITY. SAME FURNACE AS IN FIG. 1.

scaling also is liable to occur, which product acts as a thermal insulation.

23. No consideration of chamber height should be apart from the understanding that this changes in effect as the stock melts and that the best dimension satisfies the economic mean of all these conditions. Starting at the head of the chamber where the burner mouths enter, an adequate free space is necessary. This allows combustion to initiate apart from the cooling effect of the solid charge and before the thermal actions are rapidly self-accelerating.

24. Since the gas mixture is most oxidizing in character at this early point, the roof should be high enough to avoid a direct blast upon the metal. As the oxygen content decreases, the flame is brought nearer the bath by the effect of the roof slope. This also opposes the natural tendency of the heated gases to rise, especially when carried beyond the downward impetus developed by the angle of the burner mouth.

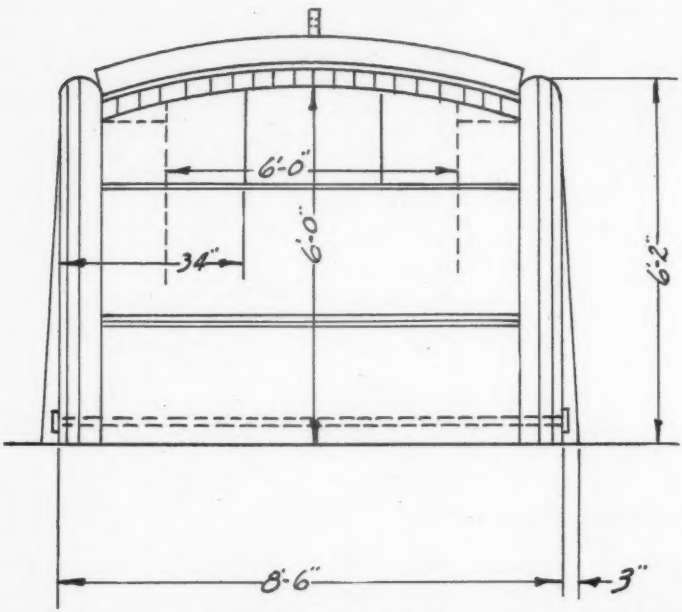


FIG. 3—END VIEW OF PULVERIZED-COAL-FIRED AIR FURNACE OF 15-TON CAPACITY. SAME FURNACE AS IN FIG. 1.

25. An additional advantage of the greater height near the earlier combustion zone is the semi-turbulent effect obtained by discharging air-suspended coal particles from the burner mouths into a free volume of greater static pressure—this pressure results from the change of velocity energy due to the increased friction of passage of the laden air.

26. Relative to the varying effective chamber height, which depends on the stock level, it is pertinent to consider that this level lowers in the approximate order that the flame radiation increases, and heat transfer by convection grows of less importance. These features change as a function of increase of furnace temperature.

27. Dimensions as shown in the accompanying sketches may be taken as fairly typical of accepted practice of its kind.

Hearth Bottom

28. The bottom of the hearth is sloped from either end to the tapping section and from the middle of this section to either tap hole. The slope, commencing at the furnace front, drops one inch in a 10-ft. length according to one practice, and 2 in. in 13 ft. from the rear bridge wall.

29. The metal depth should naturally coincide with the expected rate of heat absorption, which principle is herein followed out. The minimum slope should permit of adequate drainage on tapping, and consideration must be given to the probable regularity of the bottom which depends on (a) the bottom construction, (b) period since replacement and (c) furnace operation details.

Roof

30. Some years ago the line of the air-furnace roof presented a most fantastic appearance of a curved outline descriptively termed as "camel back." The concept of this configuration was to redirect the flame onto the bath and afford heat transfer by such intimacy. Although these "styles" refer back to the days of coal-grate firing, the newer principles of design are applicable to any combustion process.

31. In general, the roof outline is fairly simple. Near the burner mouths the line should be flat or, if desired, slightly rising away from the front. This prevents pocketing of stagnant gases at the high point and storing of heat.

32. From the level portion, which extends as far as the major combustion zone of the furnace, the roof slopes gradually down to the rear bridge wall. This gradient is in line with the hearth heights as previously discussed.

33. The roof over the flue section, leading to the stack, is raised on a steeper gradient. This purpose is simply one of economy to keep these bungs away from the flame and avoid choking the exhaust gases, which permits of better regulation elsewhere.

Front Bridge Wall

34. The location of the front bridge wall is determined by the cold space representing the mixture of powdered coal and air and initial combustion before melting temperatures are attained. The slope to the bath is such as to avoid interference with the flame and at a sufficiently steep angle to prevent a "feather edge" or thin depth of metal subject to excessive heating and oxidation.

Rear Bridge Wall

35. The same reasoning applies to the rear bridge wall. The width is ample to support the bath and prevent excessive erosion by the slag. The height of the rear bridge wall above the bath level is preferably about 4 inches, which is sufficient to prevent slopping over of the iron or slag into the flue but does not lift the gas current too high because of the inverted weir effect.

36. Any change in tonnage to be melted primarily affects only the hearth heights and that of the rear bridge wall.

37. The rear bridge wall opening is an extremely important index of the melting characteristics of the furnace. For that reason it deserves a separate discussion and will be treated later under another heading.

Flue

38. The flue from rear bridge wall to stack may be a direct continuation from the furnace, or may branch at right angles if the convenient position of the furnace does not admit of the former. There also are instances of two furnaces exhausting into the same flue and utilizing but a single stack.

39. It is good practice to have an opening in the flue controllable by a sliding door so that the flame temperatures may

be reduced with a saving of the brickwork or a back pressure set up by reducing the exhaust draft.

40. For the same reason, an opening at the bottom of the stack is commonly employed. This may be partially blocked by a crude and temporary brick work; still better practice is to use a stack door, suspended and counter-balanced. The proximity of the door to the draft heat may make such impractical because of warping, unless it is protected by a lining.

41. The furnace stack should be doubly lined with firebrick up to the height of high temperatures; beyond this the single lining is sufficient. The height of the stack has a direct relationship to the procurable draft, and the plant location may affect this also, as well as the frequency of draft variation due to weather. The diameter also concerns this feature as well as other factors influencing friction of gas passage.

Doors

42. Working doors and openings in the air furnace should be confined to a minimum consistent with adequate operation. Air leakage and local effects are liable from faulty sealing of doors and observation holes, yet these seem to be necessary provisions. While these features would be relatively unimportant in a large furnace, they constitute a much more serious loss where the air furnace is concerned.

43. Usually the doors are confined to one side (the working side) of the furnace and are two in number, one for the rear and one near the center or front. A smaller opening may be located near the burners for lighting and for barring down the stock. The larger doors are for charging the furnace by means of the peel, barring down and slagging off. Other openings are adapted to facilities of the individual foundry.

Tapping Spouts

44. Tapping spouts are placed on each side of the furnace, one at a slightly lower level than the other to carry off the last of the heat and accommodate any "over-iron." Pouring takes place from both sides and the furnace is usually located near middle of foundry for shortest transfer of iron to floors.

45. The tapping spouts, which determine the distance of the hearth bottom from the floor level, are located as to accommodate bull and hand ladles or whatever methods are employed for the conveyance of the molten metal. The tap hole diameter

is dependent on these facilities or the speed at which the iron may be conveniently removed. Diameters of ¾ inch and 1 inch are commonly employed for pouring ladles or bull ladles.

46. The tap holes are somewhat higher than the spout, which is sloped at such an angle as to direct properly but not to impede the stream. The length of the spout should be short enough to give a straight flow and minimum cooling effect. The spout angle also affects this.

47. Iron from the early part of the tap often is cold, due to pocketing in the hearth depression next to the tap hole. Ladles improperly dried or preheated may chill the first of the iron, rendering it unsuitable for pouring. For these reasons, a pour-back is afforded where the metal may be returned to the furnace.

48. The pour-back should be placed near the rear of the furnace, away from the tapping spout so as not to interfere with operations there. It is necessary for the pouring crew to mount a steel platform and stairs to return this metal. This platform is movable in order not to hamper other movements.

MATERIALS OF FURNACE CONSTRUCTION

49. The type of flame and coincident conditions with powdered coal is one of high thermal intensity coupled with great abrasiveness from the suspended ash, so that operating conditions are about as severe as any that are obtained in metallurgical practice. There also are additional factors of suddenly changing temperatures and mechanical abuse.

Refractory Shapes

50. The common refractory shapes for the air furnace are covered in a Simplified Practice Recommendation by the Department of Commerce and sponsored by many technical societies. These include:

Straights	9 x 4½ x 2½ in.
	9 x 6¾ x 2½ in.
Splits	9 x 4½ x 1¼ in.
Soaps	9 x 2½ x 2¼ in.
Wedges	9 x 4½ x 2½—1⅞ in.
	9 x 4½ x 2½—1½ in.
Arch Bricks	9 x 4½ x 2½—2⅛ in.
	9 x 4½ x 2½—1¾ in.

51. In addition to these are a 13½ in. series of square, angle, arch and arch-angle bung brick. Miscellaneous shapes consist of two sizes of door opening tiles and ¾-in. and 1-in. tap-out blocks. There also are circle brick for various circle diameters from 24 in. to 84 in.

52. Brick for side walls are preferably of a hard dense burn with a high alumina content. After a short run it will be noted that the clay bond between the brick usually has disintegrated, permitting attack on five sides. For this reason minimum bonding is desirable and the clay should possess as high refractory qualities as the brick itself. As the attack is chemical in character, machine-pressed brick or some process of equal attainment often is specified to resist the penetration of the fluxing materials.

Severity of Service

53. In respect to its behavior, we may roughly divide the brick in three general portions. The outer portion is subject to intense temperature in contact with molten ash, which makes a layer of thin wash that is rapidly wiped away by the gas flow. Next comes a larger layer which is a combination of the flux on the outside of the brick and the brick material itself, this forming a gradient of concentrations. The rest is, of course, the material proper.

54. The most important resistive material is that between the outer layer and the fire brick itself. The temperature at which this softens determines the resistivity of the brick. With high-alumina brick this temperature is high, but with high-silica brick this may be 150 degrees lower. The greater density of the brick slows down penetration, while its higher thermal conductivity acts in the direction of its acceleration.

Refractory Life Depends on Melting Speed

55. Life of the refractory depends greatly on the melting program and melting speed attained. With eleven heats each week we find it necessary to rebuild the furnace, in part, each week end. The actual life probably would be half a week more or a scant two weeks in all, but safety does not permit us to gamble on such an expected duration.

56. On a basis of a single heat per day, two or three weeks may elapse before building the side walls is necessary. This depends mainly on the extent to which the furnace is driven, i. e.,

pressure in the combustion chamber, amount of ash and degree of pulverization. A life of 30 heats for bung brick and 22 for side walls might be taken as a fair average. These estimates are for moderately hard driving.

57. The bung bricks near the high temperature zone exhibit the more hazardous life and are subject to the greatest mechanical abuse. Due to the abrasive effect of the fine ash and draft, the brick is gradually eroded away. Where the thickness approaches a minimum the bung is replaced by a new one and the older one moved back over the flues or to some location where the service is less severe.

Reducing vs. Oxidizing Atmospheres

58. A furnace operating with a reducing atmosphere is very severe upon the brick work, due to the disrupting effect of carbon monoxide which reacts in conjunction with small amounts of iron oxide in the brick to form carbon and carbon dioxide. Such formation may exert sufficient pressure as to destroy the brick. The action occurs at relatively low temperatures and is considered to be due to a catalytic effect of the included oxide.[1]

59. Highly oxidizing flames are productive of high temperatures and so are destructive of brick work. Regional melting of the stock may be coincident with local pressures or intense heats which produce failure in those parts. Distribution of the stock in charging greatly affects this.

Tests of Refractories

60. Tests of firebrick as specified by the American Society for Testing Materials are more conveniently made by the manufacturer than by the consumer. The results of such tests pertain only to the particular brick tested and may or may not be representative of the lot or following lots.

61. By visual inspection and chemical analysis, certain information may be derived leading toward some conclusion as to the quality of the brick. The following features are desirable:

(1) Consistent burn of the desired degree.

(2) Dense material.

(3) Freedom from excess fluxing ingredients and iron oxide.

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[1] Reference numbers refer to articles listed in the Bibliography attached as an appendix to this paper.

(4) High alumina content.

(5) Consistent size or dimensions; i. e., freedom from warping or need for grinding to shape.

(6) Freedom from spottedness or mixture of an uneven distribution.

(7) Manufacturing methods and raw materials conducive to high quality.

62. With respect to manufacturing procedure, it is considered best to specify machine-pressed brick where penetration of slagging materials is liable, and hand pressed where a less dense brick is preferable. The raw clay should be of an even moisture content, and exposure following mining should be at a minimum.

63. In burning the brick, the use of continuous kilns promise a more nearly consistent and better controlled product than can be obtained in circular or rectangular kilns. The moisture content contingent to repressing should be carefully controlled. In general, a minimum of water of equal distribution so as to give as stiff a mud as possible is considered the best practice.

Bung Brick

64. Bung brick have been considered to be preferably of a softer burn than those of the side walls, as the variation in temperature tends to promote spalling, to which a dense brick is most liable. However, the latest preference has been for a harder burn, as experience indicates that the mechanical strength is even more important.

65. Bungs are often so designed as to exert the maximum holding leverage at the part of greatest brick expansion and carelessness on the part of the furnace operators in tightening the bung to too great extent often results in early failure. Unfortunately, such practice is only too common.

Fluxes

66. The use of alkali fluxes to remove sulphur has developed within the last few years, and their improper application results in deterioration of the brickwork. If a large amount of fume is formed, or the action is retained in the furnace beyond the accepted period, reaction with silica or silicates occur, coincident with the reduction of the dissolved sulphur back into the bath.

67. This destroys the efficacy of the process and should not occur except through gross inefficiency. In further connection with this reaction, it must be remembered that temperature is a modifier both as to the rate and equilibrium constant or the extent of progression at any interval.

Laying Up Brick

68. There is often a regrettable tendency among foundrymen to use a too finely ground and plastic clay for slurry and laying up the brick, in order to extend the use of the same clay for ladles, patching, etc., where a workable material is desired.

69. To obtain the best results from any firebrick, they should be laid with a bond of equal refractoriness. Fine clays absorb water rapidly and have a high shrinkage on drying. The use of refractory cements containing sodium silicate and fireclay is not satisfactory for air-furnace construction, due to their low fusion point.

Air Furnace Bottom Material

70. The air-furnace bottom is usually of refractory sand. This is a fairly clean material with sufficient clayey impurities so that it frits in place on the first heat. The writer's practice is to test the sand by placing a definite volume in an oil sample bottle with dilute caustic-soda solution, vibrating the mass until the clay separates and forms a distinct layer at the top upon settling. This gives a fair estimate of the impurities on a volumetric basis.

71. Another feature affecting the fusion tendency is the fineness of the sand. The fused layer should be on the order of one-half inch in thickness, which is ample for the purpose but does not interfere greatly with its removal.

72. Some foundries make use of a brick bottom, the brick being placed standing on end. This has a long life and many claim that it is more satisfactory in that the attack is more even. Greater labor is required for its installation and removal, so it is best for furnaces run a long time between repairs.

METHODS OF FURNACE CONSTRUCTION

The Bottom

73. Proper furnace construction involves a need for qualified workmen, care and supervision rather than any particular

technical knowledge. The furnace bottom should be well tamped and free from moisture. The bottom slope may be laid off with a level and the surface smoothed down with a trowel. The sand should then be covered with flat boards to protect it from disturbance on the initial charge.

Side Walls

74. The side walls should be well laid with 9-in. straights, one layer parallel and longitudinal to the cast-iron side plates, and the adjacent layer with the brick lengths normal to the first. This gives a total thickness of 13½ to 14 inches. The foundations for the side walls extend a few inches below the furnace bottom, and care should be taken to have these level.

75. Precautions should be taken to prevent the iron from entering under the brickwork and heaving the mass. Possibilities of the wall tipping forward may be avoided by using a slight back slope. Wedge brick are placed on the top of the walls to accommodate the ends of the bungs. A slush of fireclay gives an even setting.

76. Examination of a wall under fire for several heats reveals that the bond between the brick has disintegrated or fluxed away, allowing further attack to take place on many sides. With the appreciation of this possibility, only straight and true brick are used and a minimum of material to fill the outer pores of the brick and any other minor irregularities.

77. Formerly, ground firebrick was added to this mixture to reduce shrinkage, but it is believed that unless this grog is finely ground it tends to separate the brick unduly. Only a minimum of this wash is used and the brick rubbed into position.

Bungs

78. Bungs are made up of two rows of 9-in. brick; a 27-in. width comprising three rows may be employed to advantage where the greater weight of a unit is no handicap. Similarly, two rows of 13½-in. brick may be used. In some instances a clay wash is given to the arch previous to use, but general practice does not accept this feature. Leverage used in making up the bung is of great importance, as previously emphasized.

Tap-Out Blocks

79. Special shapes consisting of tap-out blocks render unnecessary the building up of breasts from fireclay mixtures

This saves labor, but it is claimed that the block is more liable to breakage if the stream freezes or the hole must be enlarged.

80. Blocks may be obtained for either hand-ladle or bull-ladle pouring. Tiles may be used for support over door openings instead of arch brick. This saves in labor, but the tile should not be too massive or unequal expansion will result in its fracture.

Preliminary Drying

81. In a newly constructed furnace, preliminary drying previous to the first heat is not generally carried out, although the writer is acquainted with one instance where this is done. Normally, it is considered that the slow absorption of the heat by the charge prevents too rapid heating and that preheating is not economically advisable. This also renders it difficult to charge if the melting stock must be placed in a heated furnace.

CALCULATION OF THE MIX

82. The furnace mixture is calculated on a basis of the per cent of each element present in the melting stock of each kind. These are converted to pounds and should total to that of the desired entering analysis.

83. A certain amount of balancing will be necessary to make the amounts add true within the limits of permissible variation. For this purpose, preferably three pigs of different analyses should be on hand in order to accomplish the calculation easily and without greatly changing the proportions of the different stock from heat to heat.

Composition of Furnace Charges

84. The furnace charge for a malleable melt will be made up of sprue and hard-iron scrap from a recent heat of known average analysis, soft-iron or anealed scrap, pig iron and steel. The proportions should be fairly constant, as the rate of oxidation of each of these stocks varies according to the typical physical condition and combined carbon content.

85. The per cent of soft iron whose analysis will be variable, if not unknown, should be confined to a maximum of about five per cent. The sprue of a preceding heat will amount to nearly 50 per cent of the charge, assuming that a fairly constant tonnage is being maintained. The steel may be in the order

of about 15 per cent, but will vary according to the juggling of the quantities involved. The pig iron will be around 30 per cent.

86. These proportions will vary according to oxidation obtained but are illustrative of the methods. Often the pig iron of any one car or analysis will be limited to a certain fraction, with the theory in mind that any undesirable features of a particular lot will be diluted and lessened by preventing its predominance. This method is not universal, as foundrymen have come to feel more confidence in their raw stock.

87. Other furnace additions will be ferrosilicon and ferromanganese, if they are found necessary. These should be added when the iron is molten.

Entering Analysis

88. The entering analysis of the metal should equal the desired ultimate analysis plus the expected oxidation and minus the sulphur pickup. This expected oxidation should be an average of that previously obtained, corrected at frequent intervals.

89. The resulting analysis should consist of a proper balance of carbon and silicon which relates to tensile properties, scrap loss and ease of annealing; a ratio of manganese to sulphur which will be amenable to heat treatment, and phosphorus not over a fixed limit.

90. In instances where the analysis of the entering sprue is not known, an estimate may be made from a representative test sprue of the heat furnishing the sprue. Pouring a standard form and permitting it to cool under definite conditions, the character of the fracture and amount and nature of any graphitization will act as a measure of this tendency, or approximately the effect of the carbon plus the silicon. Values may be assigned various descriptions of the sprue and a system developed which will give a fair approximation in lieu of better information.

Relation of Blast Furnace Practice

91. The relationship of blast furnace practice to its product, and its subsequent reflection upon foundry scrap, has been a pertinent subject for recent discussion among foundrymen.[2] Incidents of such a relationship have been developed, and on one occasion at least, the writer was satisfied that a particular lot of pig ran proportional to the scrap resulting. A possibility exists that proper remelting might have modified the difficulty.

The consideration lies in abeyance until the causes are further studied.

Steel Scrap

92. Steel scrap generally is specified as a definite kind, such as steel rails whose analysis will be practically constant. The steel should show service to distinguish it from reject from manufacture, should be free from excessive scale or rust, consistent in nature and free from oil and grease unless a correction can be made for these.

93. One incident is known where journal boxes were added in the charge and the grease in these raised the sulphur content of the metal beyond the desired limit. The analysis had been based on drillings carefully cleaned from lubricants and no consideration of their effect was taken.

Soft Scrap

94. Soft or malleableized iron may be either foreign or domestic, the latter having the advantage of known circumstances of manufacture. The variation in analysis commonly will be such that a representative average will be used.

95. Relative to older methods of melting to analysis, it is related that one foundryman of former days, who was noted for making good iron, was accustomed to oxidize his carbon and silicon to a point where small pinholes appeared around the rim of his test piece. He then added a definite amount of silicospiegel to bring the metal back to the right point. In spite of his disregard for the modern methods of analysis, he was quite successful in this way.

FEATURES AFFECTING OXIDATION

96. The problem of oxidation within the air furnace is not essentially one of amount but rather of regularity, in order to duplicate the rate from heat to heat. However, undue oxidation results in higher refractory consumption and metal loss, greater labor in slag removal and the use of silicon and manganese as a fuel where cheaper agents could be used.

Mechanics of Oxidation

97. The mechanism of oxidation is, briefly, the attempted development of an equilibrium between the oxygen in the gas phase over the metal and the slag consisting of ferrous and

ferric oxides, with those of silicon and manganese; and these in turn with the molten iron. Carbon and silicon oxidize with reduction of ferric to ferrous oxide, which is reoxidized to its original condition by the gas stream. The nature of these reactions has been studied by others.[3]

98. The part of the charge nearest the burners is prone to the greatest oxidation, and flattening the metal to the greatest extent serves to equalize both the heat distribution and the gases rich in oxygen. Thus the concentration at any time is kept at a point where scaling will not exceed an undue amount.

99. The metal containing the more combined carbon oxidizes the most freely, as well as that offering the greater surface for exposure. All these factors should be kept in mind should conditions require a change in melting practice or melting stock.

100. If a portion of the stock is heaped to one part of the furnace so that its mass delays the melting, considerable scaling will ensue. The furnace man, by vigorous application of the bar, can dislodge the material and so hasten the fusion process. Facilities for furnace charging are not always of the best, so that inequalities in heaping the stock are quite likely to occur. Proper working then is necessary to offset such irregularities.

Carbon Oxidation

101. In a study made some time ago, the writer was able to develop that the oxidation of carbon and silicon increases with the original content of these elements respectively. This would be the rational expectation in line with the law of mass action. Manganese and silicon oxidize at rates of quite definite proportion to each other, while carbon and silicon oxidations show no clearly defined relationship.

102. Any protective effect of the silicon to the carbon would probably be clouded by the course of the furnace operations. A decrease in carbon oxidation external to changes in the charge often will be accompanied by a sulphur pickup, which is a condition indicative of coal depositing on the bath and acting as a recarburizer.

103. In a study of oxidation from the first to the last of the week, an average progressive increase was found. However, variations were so frequent and wide that the general tendency could not be used as a safe rule.

Causes of Increased Oxidation

104. Further analysis indicated that this feature probably was due to increased opening of bridge wall due to cutting of the bung and top of bridge. Possibly the presence of oxidized pools of metal in the furnace bottom may have added to this.

105. It is well known that the morning heats with a colder furnace are more prone to oxidation than those of the afternoon when the furnace has not had time to cool. Monday morning heats, which in our own practice are associated with a newly rebuilt furnace, are abnormal on account of the preliminary drying necessary. The lumber used to protect the bottom also acts as a recarburizer to some extent.

Oxidation of Silicon

106. The oxidation of silicon occurs early in the melting action, and as the temperature rises the carbon oxidation rate increases, with a consequent protective effect on the silicon.

107. The same phenomenon is even more clearly revealed in the reactions of a bessemer converter. A graphical analysis covering a large number of heats showed that the oxidation of silicon decreased with speed of heating up to some point near "melted." From "melted" to "tap" the oxidation rate of silicon decreases and that of carbon develops rapidly.

108. This characteristic is of practical value—the furnace man, by knowing whether or not the charge melts at the normal rate, can estimate his silicon oxidation accordingly. If he holds the metal at high temperatures, a high carbon loss may be expected and he should meet the situation either by reducing the heat input, or by adjusting his fuel mixture as to drop coal and recarburize the iron. A charge which requires longer than the usual period to "melted" for the tonnage concerned, may be expected to give a high silicon loss.

Causes of Increase

109. Oxidation increases with increase in driving the furnace or the amount of air for combustion forced through the chamber at any one time. This results in increased melting speed, so that the action is more pronounced in the carbon oxidation than that of the silicon—possibly, too, because of less coal dropped on the bath.

110. On occasions, an abnormally higher silicon content

will be obtained and this can be related to a strongly reducing atmosphere at high temperatures, wherein the silicon is reduced from the slag. This feature is also common to acid open-hearth practice.

Sulphur

111. In the use of fused soda ash for the reduction in sulphur, a decrease in the metal content of silicon and manganese should be expected. The amounts may depend on the application of the desulphurizer and need not necessarily be serious. The alkaline character of the flux runs true to usual reactivity

Controlling Oxidation

112. Oxidation during pouring of the heat frequently is a source of trouble, due to the high temperatures obtained in the furnace at this period. By proper manipulation this can be controlled, however. The writer has a series of analyses from 15 heats, both of the morning and afternoon and taken at weekly intervals, which show the following average oxidations from the first to the last of the pour:

Carbon, per cent	0.027
Silicon, per cent	0.015
Manganese, per cent ..	0.007

113. Skimming the slag may be carried out as soon as part of the iron is molten, in order to speed the heating effect by eliminating the slag blanket. However, if it is desired to restrain oxidation, the slag may be left on to advantage; in fact many foundries do this, skimming only just before they are ready to tap.

Slag Removal

114. The mechanism of skimming is entirely by hand and the working conditions are quite severe. A long bar with a steel strip on the end is supported and balanced by a hook suspended from above. The bar is inserted in a working door at the rear of the bath, and the slag which floats to this end under the impetus of the draft is readily skimmed and pulled out of the slag door. This drops into a slag buggy, is cooled by a spray of water and is removed to cool.

115. Slag removed at too low a temperature is inclined to hold suspended metal. This can be reclaimed to some extent

by breaking up the cold slag with a sledge and removing the larger pieces of iron. Magnetic separators are not universally employed, as good practice cuts the recoverable metallics to a negligible figure, especially where the total slag amount is small.

Slag Characteristics

116. Normally the slag volume should be indicative of the amount of silicon oxidation, as indeed has been shown by certain data. However, this is influenced by such matters as temperature, condition of the furnace bottom and firebrick, as well as melting speed and scale and sand on the entering charge. It is believed that this explains the erratic nature of results obtained from such studies as the writer has made.

117. The appearance of the slag formed may be from light and spongy to a vitreous, dense material, to a stony or tough

Table 1

CHARACTERISTIC ANALYSES OF AIR-FURNACE SLAG

	FeO per cent	MnO per cent	SiO_2 per cent	S per cent	Al_2O_3 per cent
First skim:					
1st buggy	35.45	2.99	45.44	0.069	14.65
5th buggy	29.88	2.04	49.20	0.054	17.44
Second skim:					
1st buggy	30.44	2.81	49.36	0.035	16.57

and dense character. The color may vary from a brilliant black to various intermediate shades of brown. This gives some idea of the variety of this product.

Analyses of Air-Furnace Slag

118. Characteristic analyses of the air-furnace slag may be found by Table 1. Iron oxides in these exist as FeO and Fe_2O_3, in which the former greatly predominates. For this reason the oxides of the group were all calculated as of the ferrous form.

119. The decreased oxidation of iron and manganese at the last of the first skim, and its slight increase on the second, are noticeable, as well as the progressive decrease of sulphur, which is probably a straight function of ash deposit from the coal.

120. A preliminary investigation points to the connection of atmospheric temperature to oxidation within the air furnace. As a more extended study is now under way, no report will be made at this time other than this mention.

Furnace Operations

121. As stated elsewhere, the charging and distribution of stock plays an important part in subsequent melting. It is the writer's practice to place the steel and hard-iron sprue in the foremost part of the furnace and the greater part of the pig iron in the rear. This locates the more difficult melting metal at the zone of initial higher temperatures.

122. The pig iron is placed by a peel, while the sprue and malleable scrap is handled in steel pans. The steel rails are handled individually. The charge openings are the side doors at the rear and two places at the front made by removal of the bungs.

Method of Charging

123. The charge is brought to the furnace on skid platforms by electric trucks and raised to proper height by the truck elevator. To charge through the roof, the workmen use a transferable steel platform and stairs. Unfortunately, entirely mechanical charging is not yet feasible.

124. The furnace is lighted by inserting some oily waste or bags through the light hole in front of the burners. The primary or coal-conveying air is next applied.

125. As soon as the coal flames, which is almost immediately, the secondary air is gradually applied and furnishes that required to complete the combustion. The stack smoke whitens very shortly and then becomes nearly nil.

Absorption of Carbon

126. The stock containing the highest combined carbon has the lowest melting point, which is the pig. The hard-iron sprue has the next lowest, and finally the steel.

127. Free carbon is taken into solution into the metal as the temperature rises, but some remains, it is believed, even after the iron is molten. The pig iron sweats and usually is well advanced before the other stock melts appreciably. In this consideration is the effect of stock mass, which lowers the hearth temperatures accordingly.

128. To equalize the melting process, the furnace man bars down the stock by thrusting the solid material into the molten pools for solution, generally flattening the charge as much as possible. By the use of green poles he may boil the fused metal

on to that which is still frozen and dissolve it in this fashion. Poling also has the effect of mixing the iron and raising the cold layer from the bottom, where it normally remains due to its higher density.

129. As soon as the greater part of the bath is molten, the first skim follows to assist the heat transfer from the flame. All this description signifies but one practice; others differ as circumstances dictate.

Air Control

130. As the primary air mixture is relatively constant, any variations to be made in the total air are through the secondary supply. After considerable experimentation with various coal and air mixtures, it was concluded that full air from the start gives us the best melting economy in a metal to coal ratio, as well as giving the greatest speed. The air can be cut somewhat in later stages to give a less oxidizing condition.

131. To maintain a slight pressure within the furnace, the draft can be regulated by adjusting the stack and flue doors. The operation of these is guided by pressure or suction at peep holes in the working doors along the side of the furnace.

DETERMINATION OF HEAT PROGRESS

132. As the heat advances, methods must be taken to learn this progress in order to tap at the proper interval and to make any corrections necessary. Even with highest skill and care, modifications outside the operator's influence produce small to large variations which must be expected and provisions made for their regulation.

Cup Test

133. Temperature tests ordinarily are made by the test-ladle method. A small amount of metal is scooped from the bath in a cup ladle, the whole placed within a hood as to be protected from drafts of air and the number of seconds counted until the metal surface commences to cloud. The time interval at which the ladle completely clouds over may be used also.

134. While the temperature is a function of the rejection from the metal of this cloud or slag, the writer believes that various other factors also play an important part. These may be enumerated as follows:

(1) Freshness, character and thermal conductivity of the fireclay on the ladle.

(2) Carbon content of the metal.
(3) Representativeness of sample.
(4) Atmospheric temperature or humidity.

Fluidity Test

135. Another test characteristic of temperature is the fluidity test. This is measured by a device suggested by C. Curry,[4] consisting of a spiral casting with spaced buttons. The extent to which the iron flows, in pouring this, is indicative of the fluidity and—at constant analysis—of the temperature of the metal.

Steel Rod Test

136. Steel rod tests have been suggested to determine the temperature of the iron as poured into ladles. Inserting a ⅝-in. rod into cold iron leaves a somewhat pointed end, while hot iron melts off the end, leaving it short and feathered. If the rod is inserted in somewhat cool iron to the bottom of the ladle, the maximum attack will be indicated at the middle of the mass and tapering off to both bottom and top.

137. The writer's organization has not been very successful with the rod tests due to difficulty of setting standards of measurement and duplication. Furthermore, such tests measure the iron after tapping, after which no further heating can be accomplished.

Optical Pyrometer

138. The use of the optical pyrometer, while decidedly more scientific than the other devices, also has the limitation that it cannot be used readily to determine the temperature of the melt within the furnace without special adaptation. It can be used by sighting on the metal issuing from the tap hole, but even this is subject to errors due to dust and smoke, which seem natural accompaniments of most foundries.

139. Repeated attempts to correlate apparent temperatures —as determined by the aforementioned methods—with other results have not been totally successful in the writer's experience. A method of temperature determination and recording applied to the cupola, in which a hooded thermocouple is placed over the pouring spout, has been reported by H. W. Dietert.[5] A similar installation might be applicable to the air furnace, but no such instance is known.

Test for Degree of Graphitization

140. Since primary graphitization is to be avoided in the malleable foundry, some operators are accustomed to pour test pigs and permit these to cool in sand, then noting any tendency to graphite separation. The pigs preferably should be poured in covered molds and may be about 3¼ by 3¼ in. in section and about 12 in. long, minus draft. They should be notched in the middle to aid and localize fracture.

141. Pigs should be poured at different parts of the heat in order to include the effect of temperature or other variation upon graphitization. Any such graphitizing tendency should call for tests to be made of any other castings which are of large section.

142. To gauge the approximate oxidation of carbon during the melt, test sprues are taken when the iron is first melted, and at intervals following until the heat is ready. In our practice, these testers are seven inches long and tapered slightly from two inches in diameter. Smaller pieces would have the advantage of cooling more readily and hence being more quickly available, but as the tendency to graphitize is not so great, they would be less informative.

Best Results from First Tester

143. As a rule, it has been found that the first tester taken is the most indicative of the condition of the metal. The testers are poured in sand and allowed to remain there a definite period, then are quenched in water. They are then broken and the fracture examined for graphite spots. The number and size of these are significant and may call for doping or additions to the metal if the appearance is abnormal and verified by subsequent testers.

144. Variation in height or location of fracture, even within one-half inch, affects the apparent reading of the tester. To avoid this, the test sprues may desirably be notched by so constructing the pattern and splitting it.

145. If a melting program is properly adhered to, oxidation and the resulting analysis of the melt may be duplicated with relatively small variation. Unfortunately, this may be subordinated to other features such as inadequacy of molds made to accommodate the tonnage at regular tapping time. Also, a

certain degree of skill is necesary to make adjustments if any part of the melting procedure is markedly out of line with the time schedule.

Final Analysis

146. The metal for final analysis, or that taken as representative of the heat, should be from the middle of the pour. The test sample may consist of a small block convenient for drilling. This should be free from shrinkage or other segregation. In malleable foundry practice the block consists of hard or white iron.

147. One of the biggest problems connected with air furnace practice is the difficulty of temperature determination of the metal. It is felt that investigations in this direction would be an excellent field for specific research and that great service to the industry would result from organized sponsorship of such studies.

DOPING THE MELT

148. Whenever the metal is out of bounds in respect to analysis at the tapping period, doping may be resorted to in the direction of and amount as indicated by the heat-test sprues from previous experience. To recarburize the metal, petroleum coke may be used to advantage by adding the required quantity in paper packages. Other forms of carbon may also be used.

149. Silicon and manganese additions are usually made as ferrosilicon and ferromanganese. The proper lump size of these alloys allows of quick solution without too great flotation and oxidation.

150. Green poles may be used to boil the metal and dissolve the lumps more readily. About twenty minutes is generally conceded as the minimum desirable for solution and mixing. Whenever ferrosilicon is used, ferromanganese should be added likewise, as the oxidation of the two go together.

Use of Steel Additions

151. To decrease the content of the metal in elements other than iron, steel additions may be made. The effect is one of diluting, and the chilling of the bath may result in oxidation of the silicon at the expense of the carbon. Mill scale may also be employed for the same purpose. It is endothermic in action and may result in changes in reaction rates, with the preferential

oxidation of carbon or silicon depending on whether or not a critical temperature is exceeded.

152. Recarburization may be accomplished by dropping coal on the bath, but not to a readily controllable extent. Whenever coal is so precipitated, sulphur pickup may be expected and, in fact, any sudden increase in sulphur content usually indicates this action.

153. If some doubt exists as to the required amount of doping, such as in silicon additions, these may be made in a cup ladle and the metal poured. The information derived from the tester obtained may be construed for larger quantities.

POURING THE MELT

154. Tapping the furnace is accomplished by clearing out the sand from the tap hole, then breaking through the final section. Care must be taken not to disturb the breast during this operation. If the iron freezes as to plug the tap hole, the tapping rod may be heated on the end in the bath and thrust through the solid film.

155. Boiling the metal against the tap hole by green poles may be effective also. As a last resort, oxygen may be used to burn through the hole, care being taken not to enlarge it too greatly.

156. To heat up the hand ladles, the first of the metal may be caught with these and returned through the pourback. Bull ladles then follow and supply metal to parts of the foundry away from the furnace.

Pouring on Both Sides

157. Pouring can take place on both sides. The bull ladles in our practice hold from 350 to 400 lbs. The hand ladles hold up to 80 lbs. The speed of pouring with our accommodations averages three minutes a ton and approaches two minutes with a continuous pour.

158. Values for oxidation during pouring have been given elsewhere, but candor requires the admission that this is excellent practice and may not be obtained at all times. A drop in 20 points of carbon or more can easily occur from the middle to last of the pour. To prevent this, the coal and air are decreased and back pressure created by opening the stack and flue doors. Silicon reduction is liable to occur at this period.

FEATURES OF COMBUSTION

159. The generally accepted concept of the transfer of heat to the metal in the air furnace is mainly through convection at lower temperatures and through radiation at higher temperatures. Since the radiation is a function of the difference of temperatures of the fourth power, its effectiveness grows rapidly with increase in flame temperatures.

Flame Temperature

160. The furnace roof provides a reflecting and radiating medium, especially when glazed by fused ash on the exposed surfaces. The flame itself has similar ability and the triatomic gases have high radiant properties and the diatomic less so.

161. Investigators have pointed out the criticism, however, that CO_2 and H_2O are final products of combustion and are chiefly beyond the flame proper.[6] This would also infer the best heat transfer with a short intense flame.

162. The gaseous flow within the furnace is similar to inverted hydraulic passage, according to the investigations of Groume-Grjimailo.[7] The simile is made more complex by the difference in density of gases of widely different temperatures. The effect of the rear bridge in the air furnace is comparable to an inverted weir. Further discussion would only treat inadequately of the matter in a report of this sort.

Adjustment of Burner Nozzles

163. Burner nozzle adjustment laterally should be such that if double burners are used, the streams should converge at a point where no interference with flaming or ignition will result. An unbalanced condition may be reflected in excess sidewall brick consumption if some part receives more heat and abrasion than the opposed.

164. The sloping of the burners in a vertical plane should meet the condition wherein the increased temperature of gases and resulting less density causes their lift before striking the bath. As the energy of propulsion from the burners is expended in passage, the gases are sucked from the furnace chamber by the draft created in the stack.

165. Arriving empirically at the proper burner adjustment, the proper distribution across the chamber section may be checked by a suitable device. For this purpose a wood strip may be used, with small flags suspended at short intervals along

its length. By holding this at various points, the amount of flutter across the strip indicates the gas flow in operation. This cannot take into consideration, of course, any changes due to temperatures.

Bridge Wall Openings

166. As a result of extended experiments, but slight effects of change in the furnace design were found. No material changes from the bridge wall opening were considered advisable.

167. With our construction, a bridge wall opening height of seven inches at each side and 13 inches at the center was found optimum for metal-to-coal ratio and accompanying melting speed. This gave an area of opening of about 692 sq. in. Less than this amount gave somewhat better fuel economy but slowed the melting speed too greatly. A larger opening permitted of greater speed but with high fuel consumption.

168. The inverse relationship is characteristic. In order to maintain this opening fairly constant, it was found necessary to build up the rear bridge wall at intervals throughout the week.

169. Melting speeds and metal-to-coal ratios are affected by the tonnage, both rate and ratio increasing on larger melts up to the rated maximum capacity of the furnace. With proper design, this will be the optimum and greater tonnage will give no advantage. The maximum rate of speed with the furnace shown in the accompanying sketches has been developed at 15 tons, although 17 tons have been accommodated at times.

Fuel Economy

170. Fuel economy usually is expressed in terms of pounds of iron melted to coal consumed. Such values may be taken up to the time of tapping or include the coal used during the pouring period. This latter feature is usually external to melting efficiency but is interesting from a point of view of over-all.

171. The average foundryman, when questioned as to his metal-to-coal ratio will quote, in all probability, his best or near best value. This is commendable optimism but gives no idea of an average ratio covering practical conditions.

172. Since such values depend on size of furnace, melting stock, combustion equipment, melting speed, fuel and operation —as dictated by other features in production—none will be given here. Comparison is based only on over-all economy.

POWDERED COAL COMBUSTION

173. According to current appreciation of the mechanism of combustion of powdered coal, this action is divided into several stages. These stages do not necessarily occur in series of definitely defined steps, but may overlap to a great extent. The order may be expressed in the following arrangement:

Endothermic Reactions
(1) Drying to remove moisture.
(2) Heating to drive off volatile matter.

Exothermic Reactions
(1) Combustion of the volatile gases.
(2) Primary, additive oxidation of the coke (non-volatile matter of the coal).
(3) Oxidation of the coke at such a rate as to constitute ignition.

174. In order to make the best application of the combustion processes, it is necessary to have a luminous flame of high thermal intensity to create a large temperature difference between it and the stock. The higher the flame temperature, the greater the heat transfer and the shorter the flame length which effectively should extend only across the combustion chamber. To reduce the stack losses to a minimum, a rapid liberation of heat is necessary in the air furnace.

Factors Controlling Rate of Thermal Transfer

175. The features which concern the rate of thermal transfer are:

(1) Per cent of volatile matter.
(2) Moisture content of fuel.
(3) Air proportion in consideration of attendant features.
(4) Degree of turbulence.
(5) Temperature of combustion air.
(6) Degree of pulverization.

Volatile Matter

176. The volatile matter of the coal determines its approach to gasification with rapid oxidation of the hydro-carbons evolved. Their combustion also aids that of the non-volatile fuel.

Moisture Content

177. Moisture content of the coal is more important in a straight-line, short-travel chamber like the air furnace than in other heating furnaces where the heat transfer may be more readily extended. However, no difficulties may be expected in keeping the moisture under a required value with average practice.

Air

178. The amount of air for combustion concerns both the degree of cooling of the flame on entrance to the reaction chamber and the amount of sensible heat removed in the waste gases. To supply a unit of oxygen requires four additional units of other gases, which play no part other than to dilute the reacting constituents and act as thermal carriers to the stack. Less than the theoretical quantity of air to complete the combustion implies a loss through unconsumed fuel.

179. As a strictly theoretical amount of air may not always assure of combustion completed within the proper interval, in practical operations an excess of air is sometimes advisable. Obviously this should be maintained at a minimum for best over-all efficiency.

180. Due to the diluting effect of inert gases and the interfering envelope of combustion products surrounding the coal particle, oxygen present does not always infer oxygen available. For this reason a slight excess may be necessary.

Degree of Turbulence

181. In ordinary grate firing, the fuel is held stationary and the oxygen passed through the mixture. Intimacy of contact is dependent on surface exposed and volume passing per coal unit.

182. In pulverized coal combustion, the problem is complicated by the conveyance of the coal at velocities near that of the air—velocities implying both direction and rate. To acquire continued contact with fresh oxygen and removal of oxidized or inert gases, relative motion is necessary either by difference in speed or cross flow.

183. The slowness of travel of coal particles is limited by the point at which they cease to be suspended. This is dependent on fineness of the fuel, static pressure of the medium air and its

velocity. The factor of turbulence adds to the total path of the coal before emptying into the flues and increases its liability to total oxidation previous to this.

184. Avoidance of a straight-line flow should be observed as much as possible within the limitations of the furnace design. The cutting down of the bridge wall opening probably adds to the turbulence created by the effect of decreasing the stack induction.

Temperature of Combustion Air

185. Preheating of the primary air is not feasible, and such treatment of the secondary air meets with mechanical difficulties. However, the advantages are obvious and well recognized by combustion engineers. A practical solution to this problem would be a distinct technical advance, and would add greatly to present efficiencies.

Degree of Fuel Pulverization

186. Degree of pulverization is the multiple of exposed fuel surface to the available oxygen. It acts in the direction of and supplements turbulence. The limit is defined by grinding economy from an over-all point of view, considering the resultant combustion obtained.

187. Theoretical matters of powdered coal combustion have been ably reported by Dr. Rosin;[8] in his work he treats of the dual role of temperature in affecting the combustion rate, as well as other phenomena.

FUELS

188. In air-furnace practice it is agreed generally that highest economy results from the best commercial bituminous coal possible. Acknowledging the possible merits of other coals, the following analysis may serve as a guide for a suitable fuel:

Calorific value, B.t.u.....	14,000	Minimum
Volatile matter, per cent...	35	Minimum
Ash, per cent.....	6	Maximum
Sulphur, per cent.....	1	Maximum
Moisture, per cent.....	3	Maximum

189. Screen tests of the powdered coal should be made at regular intervals to check on the economic grinding speed for the material involved, or to denote excessive wear of grinding

parts. The commonly stated fineness for efficient furnace operation is 85 per cent through the 200-mesh screen.

190. Some recent opinions have been to the effect that the coal passing through the 100 mesh is more important, since this represents a sort of critical fineness beyond which no difficulty is likely in rapid combustion. The degree of fineness greater than the usual range has only an economic limitation in the extent of pulverization desirable.

Drying of Coal

191. Drying of the raw coal apparently has its main benefit in greater ease of pulverization. Powdered coal, however, is highly prone to moisture pickup and—both for purposes of more

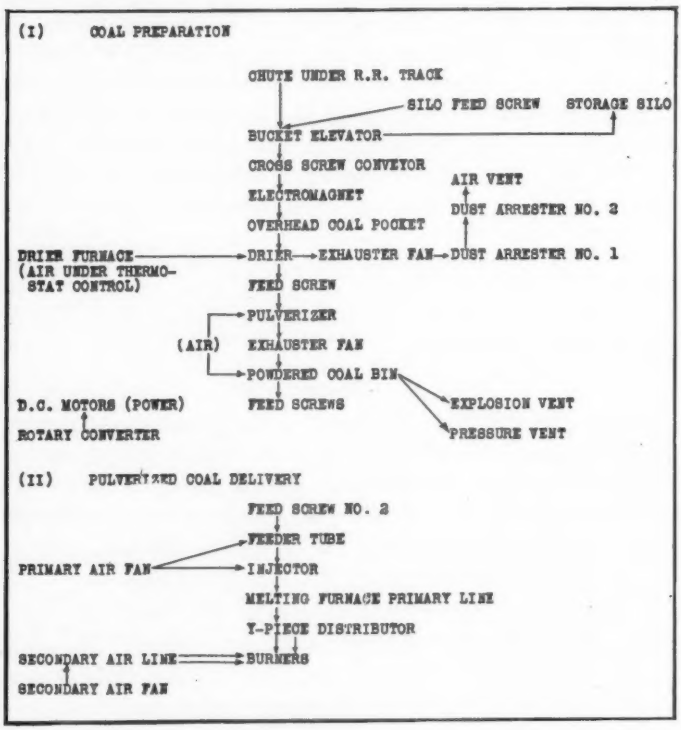

FIG. 4—FLOW SHEET OF COAL-PULVERIZING SYSTEM FOR AIR FURNACE.

efficient combustion and to prevent undue packing in storage—should be kept at a low water content. Under 1.5 per cent moisture of physical combination will offer no serious difficulties.

192. The drying of the raw coal should generally be around 250 degs. Fahr. Much greater temperatures will result in some distillation of volatile matter, with its attendant danger of ignition.

193. The fusion point of the ash from the coal is important, and its significance depends on other factors such as the amount of cooling in the flues. The ash should be sufficiently refractory as to avoid choking the flue or agglomeration affecting its flotation from the stack.

194. While wishing to avoid any discussion of equipment, the accompanying flow sheet (Fig. 4) is included to show a typical arrangement of coal preparation in a central system for pulverized coal. The items are practically self-explanatory.

BATH REACTIONS

195. The chemistry of the melting process within the air furnace must be studied only by analogy at present. No published consideration of the bath reactions is known, and all hypotheses must be based on what we have learned from similar melting procedures. Of these, the acid open-hearth has the nearest relationship and stands in the position of a big brother.

Materials Affecting Bath Reactions

196. In the treatment of the bath chemistry it is essential to enumerate the inter-acting substances involved and their sources. These are as follows:

(1) Alumina and silica from the refractories. With these are small amounts of alkalis or other compounds as impurities in the brick.

(2) Silica from the furnace bottom.

(3) Iron from the charge, holding carbon, silicon, manganese, sulphur, phosphorus and minor elements.

(4) Ferrous and ferric oxides, as the magnetic and the free ferric oxide. These appear as usual accompaniments of the charge.

(5) Silica accompanying the sprue in the charge if this portion has not been tumbled.

(6) Silica from the powdered-coal ash.

(7) Carbon from the fuel.

(8) Oxygen, carbon monoxide, the dioxide, nitrogen and water as hearth gases.

197. Of these, the refractories and part of the stock before melting all of the charge exist as a solid phase, the slag and metal as liquid, and the air and its combustion products as a gaseous phase. All of these, it will be noted, are subject to heterogeneity of components.

Oxygen and Oxides

198. Oxygen acts upon the cold charge, converting the iron to scale, usually in the form of Fe_3O_4. As the temperature rises, the oxidation may be expected to advance, as indicated by increasing slag volume.

199. The ferric oxide in presence of the molten iron probably will be reduced in part to FeO. A portion of this will dissolve in the bath and the rest in the slag, according to differential solubilities in these adjacent solutions. The extent of the decomposition of the ferric oxide will depend on the approachable equilibrium at any specific moment.

200. This will be modified by temperature, chemical nature of bath and the slag, diffusion rate—particularly in relation to the reaction velocities—and inhibiting features relating to the mechanics of the transfer. A complete formulation of these affecting matters is limited by our ignorance and their probable multiplicity.

Effect of FeO

201. FeO may be expected to combine either with carbon or silicon and manganese, depending on the bath temperature and mass effect; i. e., the relative proportions of these elements. The extent of the reaction is dependent on the oxide solubility, which is increased by additional temperature and decreased by carbon and silicon content. This feature is pertinent in practical operations.

202. We may consider a system starting with a gaseous phase of oxidizing oxygen, carbon dioxide and moisture or its dissociated products. This at any instant is striving to acquire equilibrium with the slag and assumedly in the direction of increasing Fe_2O_3 in respect to FeO.

203. The slag is decreased in free FeO by combination with silica from the ash, refractories and other sources. It is also impoverished by continued partition to the bath. In the bath

inteslf, FeO is acted upon by carbon or silicon, depending on circumstance, previously related.

Silica

204. Silica formed, enters and helps change the character of the slag while the carbon monoxide evolves to burn to the dioxide, this evolution being repressed by the viscosity of the slag blanket. In view of reaction tendencies it must be retained in mind that they are affected by the least mobility of any dependent reaction throughout the series.

205. We have seen the effect of temperature where, under favorable conditions, reversal of the ordinary actions occur and silicon may be reduced from the slag to the bath. Velocities of reaction are variable as well as rates.

206. When the slag is skimmed, we have for an instant the hearth gases in contact with the molten metal; then an oxide film tends to form. This may be considered as a type of slag of different physical properties than that hitherto considered, in which the ferrous oxide having less available silica present is more reactive to the carbon of the bath.

207. Slags first formed are subject to heavy silica and oxide additions from the scale present. These would then have the slowest approach to equilibrium with components present.

208 No consideration has been made of the temperature gradient from the top to bottom or to different parts of the bath, but undoubtedly there is this effect. In likening the air furnace to an open hearth, it must be remembered that in the latter the metal volume is small in proportion to the side-wall and bottom contact and probable attack.

Modifications of the Air Furnace

209. An installation by using the cupola in conjunction with the air furnace in a duplexing operation has been reported. Unfortunately, the writer has not the reference available for description. In Germany the Wüst furnace has been developed and one of a single-ton capacity used in the foundry of the Maschinenfabrik Esslingen.[9]

210. The relationship of this to the air furnace exists in the use of an oil-fired reverberatory with a shaft furnace on the end which empties onto a slope to the bath. The shaft enters into a preheater for the combustion air. The combined values of the cupola and higher temperature furnace are said to be obtained.

ACKNOWLEDGMENTS

211. Acknowledgment and thanks are due to Robert E. Bryant, vice-president of the Jefferson Union Co., for assistance and direction in much work from which the information in this paper is derived. Further acknowledgment is made to Chas. H. Stebbins, president of the same organization, for interest and encouragement prompting specific studies upon which the writer reports.

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[8]P. Rosin, Dr. Ing, *The Thermodynamics of the Combustion of Powdered Coal.* Report on Second International Conference on Bituminous Coal (1929), p. 838.

[9]*The Wüst Oil-Fired Furnace.* Engineering, Nov. 20 (1925), p. 653.

Some Considerations in Gating and Pouring Castings

By E. V. Ronceray,* Paris, France

Abstract

The author's purpose is to review considerations of gating and pouring castings and to bring out new factors. A casting, to be satisfactory, must be sound and free from internal strains, and must have the desired physical properties and be as low in price as possible. Four conditions under which there would be no piping are stated to be: (1) When there is no change in volume; (2) when the mass of the casting is of constantly uniform temperature; (3) when the mass is of unequal temperature with the cooling progress by parallel layers, and (4) when feeding the heads and churning or pumping the metal prevents shrink cavities. The author proceeds to show how various methods of gating produce results approaching one or another of the four conditions mentioned above. Further methods used to prevent inclusions of slag or dirt in the casting are discussed. Illustrations are cited of heavy castings made using no risers, satisfactory results being secured by proper control of temperature and speed of pouring, and by proper evacuation of gas from the mold.

1. It is our purpose in this paper to attempt to review and, if possible, to shed light on various points involved in the general methods and conditions of pouring and feeding castings. This is a large undertaking, but perhaps our endeavor will promote discussion and exchange of knowledge and open the way for further improvements.

Definitions

2. To avoid any misunderstandings, we shall use the words *sprue, runner, gate, riser* and *feeding head* with the following meanings:

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(a) *A sprue* is a channel (generally vertical) intended to lead molten metal from the outside of the mold to the inside, generally (but not always) to a joint of the mold or to the casting cavity itself.

(b) *A runner* is a channel joining the sprue to the casting cavity, either direct or through another channel.

(c) *A gate* is a channel adjoining on one side the casting cavity and either a sprue or a runner on the other side. Both runner and gate generally (but not always) follow the joint.

(d) *A riser* is an extension of the casting, intended to collect slag, dirt, dust, etc., also to let air escape from the mold during pouring. The riser may be either open or temporarily or definitely blind. In the latter case, it is not intended to let air escape.

(e) *A feeding head* is an extension of the casting intended to feed the casting during solidification so as to compensate liquid contraction. It may sometimes be composed of the sprue, runner and gates, partially or entirely.

Contraction, Shrinkage and Solidification

3. Most of the molten alloys used in the foundry decrease in volume and increase in density during cooling and while approaching solidification. This is what is termed "liquid contraction." There is also a change during solidification and another change after solidification during cooling to room temperature. These three changes are finally in the way of a reduction in bulk, except in a few cases.

4. The volume change from solidification to room temperature has been fairly well studied.[1] Wüst and Turner have given curves for cast iron showing several arrests or even expansions. Bauer & Sipp, Murray, Ewen and Turner and others have studied different alloys.

5. Liquid contraction and solidification changes have not been so well studied, for the work is much more difficult. However, data are available for a good many comparatively low-melting alloys, while research is progressing on cast iron.[2]

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[1] *The Metallurgy of Iron*, T. Turner. Ch. Griffin & Co., Ltd., London, p. 277.

[2] C. M. Saeger, Jr., and E. J. Ash, *Methods for Determining Changes Undergone by Metals and Alloys During Casting*. Amer. Foundrymen's Assn., Preprint 30-25 (1930).

6. When this research work is completed, no doubt we shall be better able to understand the process of solidification, and it will lead to further improvements in foundry practice.

An Ideal Casting

7. A casting, to be satisfactory, must fill the following conditions:[3]

(1) Be sound.

(2) Be free from internal strains.

(3) Have the desired properties (strength, composition, etc.).

(4) Be as low in price as possible, consistent with above conditions.

8. Soundness is the primary condition and a most important characteristic. Reasonable soundness is required, for the lack of such a characateristic means a lost casting, whatever be the strength of material or low cost.

9. For certain classes of castings—especially large, thin ones, with unequal thicknesses—the matter of internal strains is very serious. However, in recent years, means have been developed to counteract the strains by heat treating or slow cooling[4] from about 600 degs. Cent. (1112 degs. Fahr.).

10. Consequently, all efforts must be made to produce castings as sound as possible at a minimum cost. This simple proposition embodies all the knowledge available in foundry practice and includes gating, risering and feeding castings, a discussion of these factors being the main purpose of this paper.

FACTORS AFFECTING SHRINKAGE

11. It is well known that an ingot, the simplest of all castings, has a tendency (while cooling) to show a hollow part which is the result of all influences acting on it—effect of mold sides, method of pouring, temperature of metal, method of feeding, etc. The procedure is well known.

12. Numerous processes have been devised to reduce the hollow part in such ingots, because such defects impair commercial value and reliability.

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[3] E. V. Ronceray courses, Paris Foundry High School. *The Foundry and the Drawing Office.*

[4] A. Le Thomas papers at Paris conventions, 1928, 1929. Bulletin de l'Association Technique de Fonderie, October, 1928, and September, 1929.

13. The conditions under which there would be no piping or shrinkage in an ingot or casting are as follows: [5]

Condition 1—If there was no change in volume.

Condition 2—If the mass was constantly of equal temperature: the volume changes would take place at the same time on the whole mass.

Condition 3—If, although the mass is of unequal temperature, the cooling would progress by parallel layers (horizontal, for instance).

Condition 4—If the cavities formed by liquid contraction were filled during the cooling (using such preventions as feeding heads and pumping).

[5] A. Portevin, courses to the Paris foundry high school. *Lessons on Metallography.*

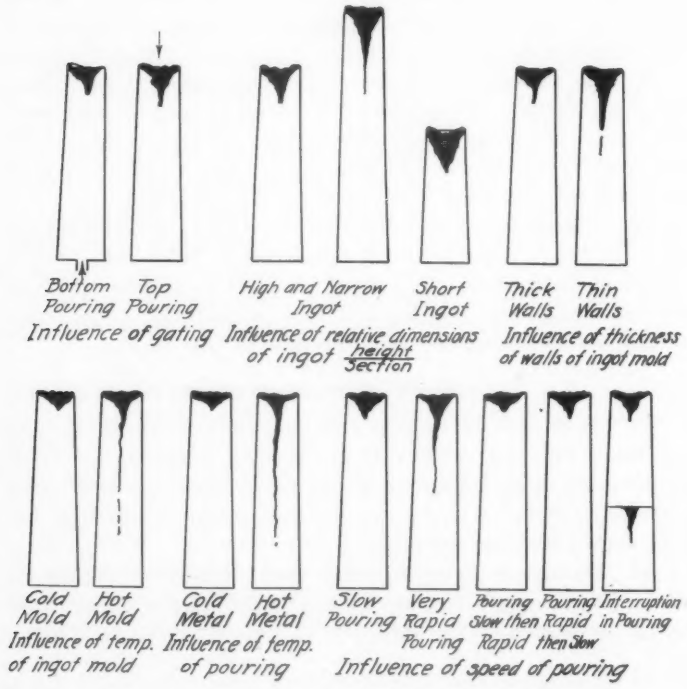

FIG. 1—FACTORS OF INGOT MOLDS INFLUENCING SHRINKAGE

14. The shrinkage in a mold is the volume change occurring from the end of feeding till complete solidification. It is contained in a zone enveloped by the isotherm lines.

15. If there was no action of gravity nor influence of gating or feeding, it would be central. To avoid the cavity in the casting, the process consists in altering the isotherm lines so as to throw the contraction void away from the useful part of the casting.

Three Ways to Combat Shrinkage

16. The means to obtain these results are:

(a) By heating certain parts of the mold (metal stream, position of runners, reduction in conduction power of mold sides, for instance, dry sand or core, etc.).

(b) By cooling certain parts of the mold (chills, cooling ribs, nails, etc.)

(c) By pumping with feed rods.

17. The above mentioned information will enable us to understand the reason for location of shrinkage holes in ingots as shown in the sketches of Figs. 1 and 2. We therefore have some information about the conditions which we have to meet in order to have a sound casting. They are not always easy to meet.

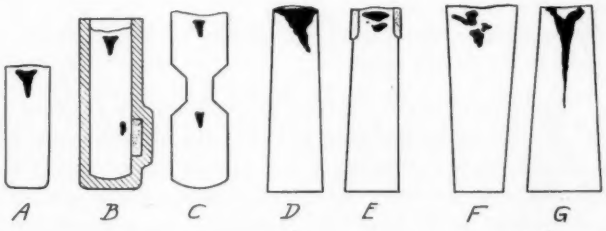

FIG. 2—FACTORS OF INGOT MOLDS INFLUENCING SHRINKAGE. *A*, *B* AND *C* FROM BRINELL; *D* AND *E* FROM TERRENOIRE WORKS, 1870.

A: NORMAL INGOT.

B-E: DEFORMATION IN EQUALITY OF TEMPERATURE MASS—

B, BY PLACING SAND IN INGOT MOLD SIDE;

C, BY MODIFICATION IN SHAPE OF INGOT MOLD;

D, BY ALTERING COOLING SPEED ON ONE SIDE;

E, BY USING REFRACTORY HEAD ON INGOT MOLD.

F, G: INFLUENCE OF INGOT SHAPE—

F, INVERSED INGOT MOLD:

G, STRAIGHT INGOT MOLD.

18. For instance, many castings are of the character of ingot *C*, Fig. 2, in which case it is very difficult to feed the lower part of the mold when the middle section has set. The ingenuity of the foundrymen must be awakened to find remedies.

Principal Types of Gating

19. Having seen what conditions must be faced in order to avoid—or rather, trying to reduce shrinkage—let us see what are the principal methods of pouring. These are:

(1) Down gating.
(2) Top gating.
(3) Combination of above methods.

20. All of these methods have their advantages and their drawbacks. Top gating is most liable to entrain the sand and produce cold shots. It may cause displaced or washed cores, but the sprue weight is always less than with down gating, and with proper dimensions may serve as a feeding head. The hottest metal is at the top, where hot metal generally is needed.

21. The down gating is less liable to cause washing of sand and is often preferred for deep molds, but it brings the hottest metal at the bottom and in many cases favors shrinkage (see first ingot, Fig. 1). This gating is not so simple as the top, and it requires a heavier weight of sprues, hence its higher cost.

22. Sometimes, by a combination of the above methods, the bottom gating is arranged to bring the metal in the mold at different heights, in which case the feeding is better but the cost higher.

Chief Precautions Necessary in Gating and Feeding

23. So far we have considered only the question of a clean metal, having no occluded gases and poured in a neutral mold, i. e., not liable to produce any gas or other defects—conditions never obtainable in the foundry. Although this is somewhat out of the scope of this paper, it appears necessary in order to survey the field quickly and to understand better the chief precautions necessary in gating or feeding.

24. Metal always contains more or less gas, either resulting from internal chemical reactions (for example, oxidized steel) or dissolved gas from various sources. The solubility of these gases varies according to temperature and pressures, so that in many cases their evolution during the solidification process,

under changing conditions of temperature and pressure, brings complications. Sometimes it develops an apparent increase in volume (for example, mushroom action in steel), and sometimes it produces holes of various kinds.

25. Other sources of gas are to be found also, namely, those produced by the distillation of substances in molds and core sands when brought into contact with the molten metal. Although it is not generally realized, a portion of these gases always penetrates into the metal.[6] Sometimes such penetration continues until solidification producing the "Leonard effect," scabs, boiling, etc., which cause losses.

26. If a sound casting is to be obtained, these points have to be watched. Attention is called here to the fact that the above causes often are confused with real shrinkage cavities.

27. Other points also are of importance, for instance, what the author has christened "effect Custer," which occurs when cold sulphurous iron during pouring entrains air in the mold. Slag inclusions, loose particles of sand, etc., also can be detrimental. It would take too long to discuss all these points in detail here, but they are very important and those interested can find reference to the subject by reading records of the Paris Foundry High School, where these points are studied in the summaries of lessons.[6]

28. Coming back once more to the conditions to the filling and feeding of a mold, it is apparent that proper care must be taken along the following lines:

(a) To fill the mold with clean metal which has little or no tendency to evolve gas.

(b) To avoid entraining slag, dross, dirt, etc., or to stop such before entering the casting cavity.

(c) To put in the mold sufficient pressure to hold in solution occluded gases and to resist the pressure of gas generated by heat in molds and core materials.

(d) To meet Condition 4 of Paragraph 13 (above) in order to avoid shrinkage holes.

Clean Metal Most Important

29. The first point is to have clean metal and take care to keep it clean till it is in the casting cavity of the mold. For

[6] E. V. Ronceray courses, summary on *Defects on Foundry Castings*, vol. 1.

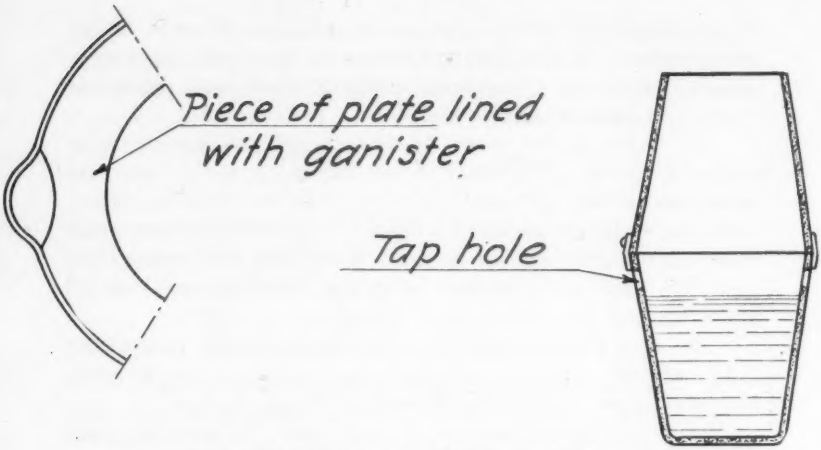

FIG. 3—SKIMMING LADLE, FOR SKIMMING OFF SLAG.

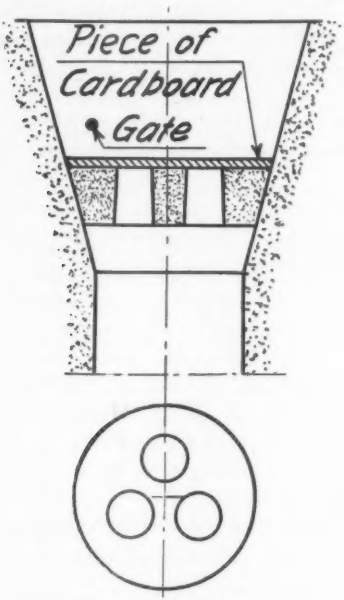

FIG. 4—FILTER OR STRAINER POURING CORE, USED WHEN ESPECIALLY CLEAN METAL IS DESIRED. FILTER CORE IS COVERED WITH A CARDBOARD WASHER TO PREVENT SLAG OR DUST FROM ENTERING THE MOLD. CARDBOARD BURNS AFTER STOPPING FIRST STREAM OF METAL, AND DIRT OR SLAG FLOATS ON TOP.

cast iron, it is the common practice of the author to use the syphon-brick in the cupola which has been so often described in the technical press.[7] The iron then is practically clear of slag.

30. An additional precaution is to use a skimming ladle (Fig. 3), which is much simpler than the "tea pot" ladle. Finally, when the work is especially important, and also when slow pouring is desired, a strainer pouring core is used (Fig. 4).

31. When greater precautions are needed, this filter core is covered by a cardboard washer to prevent any particle of slag or dust penetrating into the mold. The cardboard burns after having stopped the first stream of metal, and dirt or slag floats on the top. This filter also fills other purposes, as we shall see later.

Pouring Basins and Skimmer Gates

32. Various basins are used also to fulfill the same purpose. These include the plug basin (Fig. 5), the Schneider basin (Fig. 6), the Van Riet (Fig. 7), and others; the principles of which are easily understood on studying the sketches. The idea is to keep the basins full of metal during pouring.

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[7] Fonderie Nouvelle, January, 1922; or E. V. Ronceray lessons to Paris Foundry High School, *Melting Iron in the Cupola.* (J. E. Hurst, Penton Publishing Co., Cleveland, Ohio.)

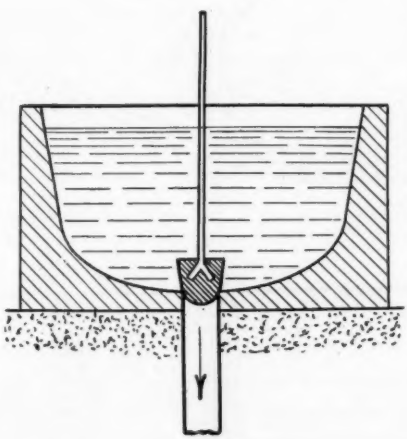

FIG. 5—PLUG BASIN. BASIN IS KEPT FULL OF METAL DURING POURING, SLAG OR DIRT FLOATING ON TOP.

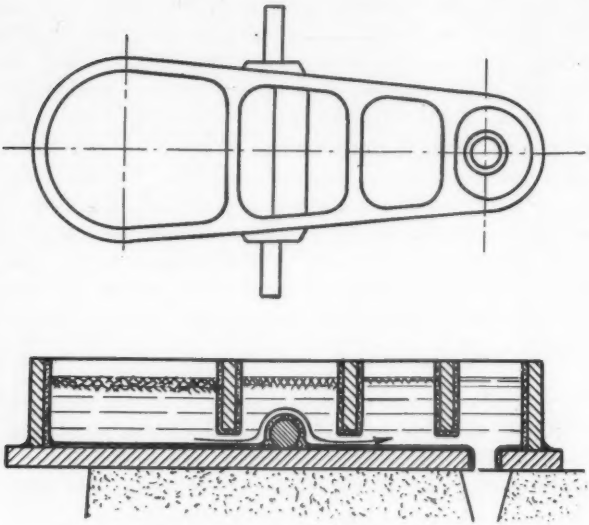

FIG. 6—SCHNEIDER SKIMMING BASIN.

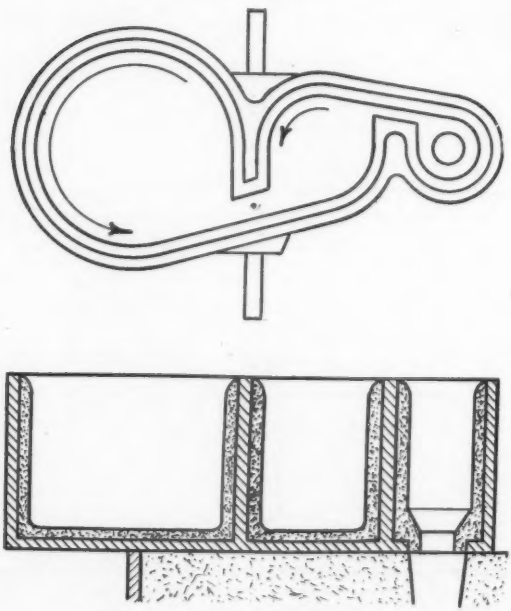

FIG. 7—VAN RIET SKIMMING BASIN.

33. Various methods also are used to arrest or collect any slag, dirt or dust which has penetrated or is formed in the mold, by such means as the ascending gate (Fig. 8), the crooked gate (Fig. 9), the centrifugal gate (Fig. 10), or filter core in the mold. The idea is to separate by some means the lighter impurities from the metal and to retain them outside the casting.

The "Leonard Effect"

34. Altogether apart from these precautions, special care must be taken to avoid the gas effects mentioned above. The "Leonard effect" is avoided by taking special care to give sufficient permeability to parts of the mold, which are submitted to

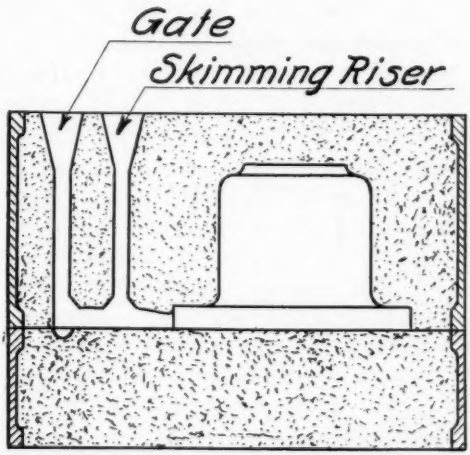

FIG. 8—SKIMMING RISER WITH ASCENDING GATE, FOR ARRESTING OR COLLECTING SLAG OR DIRT WHICH ENTERS THE MOLD IN POURING.

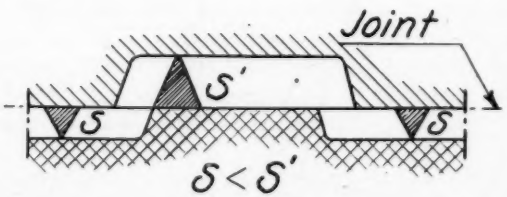

FIG. 9—CROOKED GATE, FOR TRAPPING SLAG OR DIRT WHICH ENTERS THE MOLD IN POURING.

great heat—for instance, a thin part of sand largely surrounded by thick sections of metal.

35. In this connection, a down sprue must not be placed too near a casting. Many defects come from this cause and escape observation because the castings are examined when the sprues have been separated.

36. For the same reasons, castings must not be placed too close to each other in a mold, because the sand in between two castings can be heated to such a degree as to force gas in the mold during the solidification process. It always is advisable to take special care to vent properly such congested places and to use at these places a very open sand or even a dry-sand core carefully vented.

37. The other gas effects are met by using sand as permeable and as dry as possible, by proper venting, by proper distribution of metal in the mold—in order to divide the amount of molten metal passing a dangerous spot, by having sufficient head of metal, and sometimes by using material not liable to

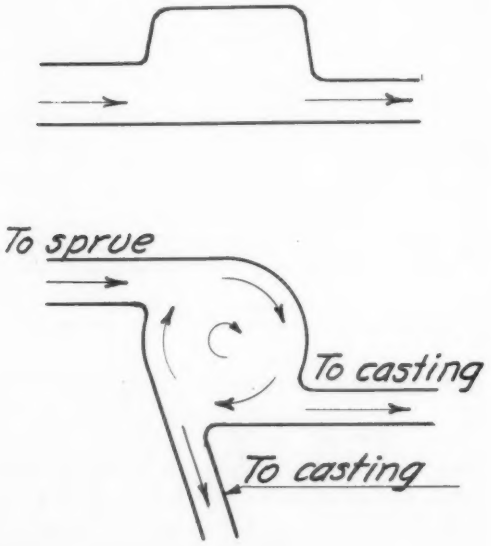

FIG. 10—CENTRIFUGAL GATE, FOR COLLECTING SLAG OR DIRT WHICH ENTERS THE MOLD IN POURING.

produce gas (such as chills or special refractory materials).

38. The above precautions practically cover points (a), (b) and (c) of Paragraph 28, above.

39. It remains, then, to study the best means for covering point (d), Paragraph 28—i. e.., the best possible arrangements of gating and feeding.

40. In previous papers[8] the writer has shown results which have been obtained without attempting to explain why these results were obtained. Those interested may refer to these papers. Years of thought have led the writer to find reasonable explanation for most of the facts, and in some cases have led to the belief that better methods could be used to obtain good castings with more certainty.

Feedings Sometimes Eliminated

41. In such papers it was explained that a certain number of castings could be made without feeding heads, and it is now possible to understand the reasons. The writer must point out here that he does not consider the elimination of feeding heads as an important result to obtain, especially in cheap alloys, but he believes that the experiments are useful for improving the conditions of gating and feeding so as to approach the ideal of the manufacture of sounder castings.

42. Many feeding heads are used indiscriminately and very often do more harm than good. As a first result it has enabled him to differentiate between shrinkage holes and other gas troubles that are so often confused with shrinkage, with the result that better conditions of sand preparation, venting, cleaning metal, etc., have resulted.

43. Also, the writer must mention that, in spite of his efforts to avoid it, certain arrangements of gating are spoken of under his name. He calls the attention once more[9] to the fact that he claims no personal credit for these methods. Most of the facts brought out are other people's ideas.[10] The writer merely tried to correlate these ideas so as to throw light on an obscure part of the foundry trade.

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[8] *The Foundry*, Oct. 15, 1922; Foundry Trade Journal, June 1, 1922, and April, 1923; Fonderie Moderne, May, 1921, and January, 1923; Revue de Fonderie Belge, February, 1923.

[9] *The Foundry*, October 15, 1922, p. 828, second column.

[10] *The Foundry*, October 15, 1922, p. 828, third column.

Three Essential Considerations in Pouring

44. The main factors that are to be considered in the pouring of castings can be enumerated as follows:

(1) Temperature of pouring.
(2) Speed of pouring.
(3) Gas evacuation off the mold.

45. A few words about each of these factors perhaps will help to a better understanding of the different methods of gating.

Temperature of Melting and Pouring

46. First of all, the temperature of melting must be such that the qualities of the metal are at their best. This varies with different alloys. Some must be melted hot and cooled before pouring; some must not be heated above certain temperatures.

47. Knowledge as to these conditions is generally available. Such knowledge, however, is not available about the best temperature of pouring, which varies largely with the shape and size of castings.

48. It can be said that, above all, the temperature must be high enough for the metal to fill the mold entirely; and, outside of proper gating, this evolves the notion of "coulability,"[11] which may be said to be the sum of actions concurring to the property of metal to fill a mold (temperature, composition, viscosity, etc.).

49. At the same time, the temperature must not be too high, not only because the strength very often decreases as the pouring temperature increases, but also because the higher the pouring temperature, the higher the liquid contraction and action on sand.

50. To sum up, the metal must be melted at a given temperature, which depends only on the nature of the metal and the pouring made at another temperature, which depends more on the nature of the mold and the casting.

Duration of Pouring

51. Some writers[12] have tried to establish a formula for determining the duration of pouring or size of gates for a certain metal in conjunction with the weight of castings. We ourselves have tried to do this, but in thinking the matter over more care-

[11] C. Cury, *Test Bars to Establish the Fluidity Qualities of Cast Iron.* TRANS., Amer. Fdymen's Assn., vol. 35 (1927), pp. 288-305.

[12] H. W. Dietert, *On Gating Iron Castings,* TRANS., Amer. Fdymen.'s Assn., vol. 34 (1926), pp. 1035-1048.

fully, we came to the conclusion that, although these formulas can be useful and must be taken into consideration when they apply to well defined classes of castings of similar thickness and sizes, they can lead to grave errors when an attempt is made to generalize them.

52. Not only the length of time of pouring must be changed with the nature of casting, but due consideration must be given to the method of gating and feeding.

53. A short pouring time may be the result of a method using numerous and wide gates, with the result that the velocity of the metal stream, at each point of gating, is small. On the contrary, a long pouring time may be the result of passing a large amount of metal at great speed in a narrow gate.

54. The pouring must be made in such a way as to fill the mold entirely with metal of a certain "coulability." The speed of the stream must not be too great in order that washing away of sand surfaces may be avoided. On the other hand, if the pouring is too slow, it can produce scabs by heating the cope of a large mold for too long a time.

55. Also, the pouring must be made in such a manner as to reduce and do away, if possible, with the necessity of special means of feeding to take care of liquid contraction. Although it is very difficult to express these different needs by means of figures, taking them into consideration permits a considerable enlightenment on the pouring phenomenons.

Removing Gases from Mold

56. It is generally admitted that risers—or, as they are sometimes called in certain cases, "whistlers"—are useful for permitting air escape from the casting cavity. Except in very few special cases, the writer believes that risers are not necessary to perform this function. He believes that in almost all cases, the permeability of the sand or other ways of escape are sufficient to let air from the above source to be evacuated without affecting the casting.

57. He also believes that, in not a few cases, pressure established in the mold through the entrance of metal, heating of air and resistance to its escape, are useful in avoiding metal turbulence or violent current of air through risers which tends to entrain dust or even disturb some parts of the mold.

58. Defects are frequently found, by reason of this fact,

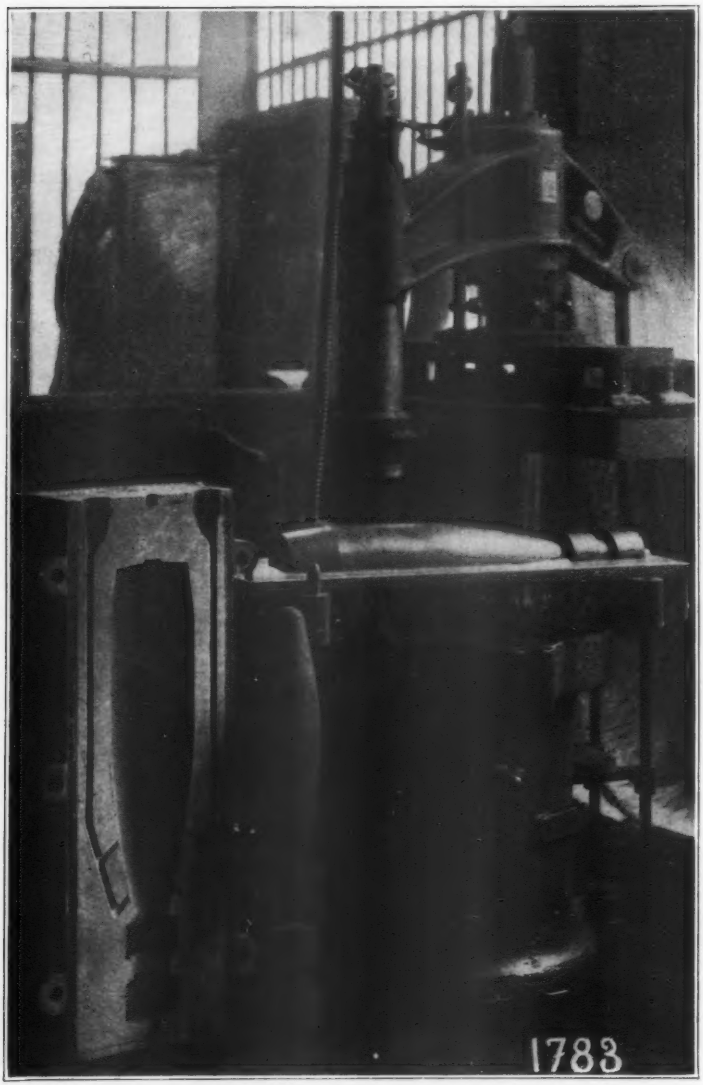

FIG. 11—MOLD FOR SEMI-STEEL SHELLS MADE DURING WORLD WAR, SHOWING DOWN GATE OF SMALL SECTION, GIVING SLOW POURING.

near risers. When risers are considered to be useful, either for collecting dirt or to show when the mold is full, it always is advisable either to cover them with a plug of sand or clay—which is lifted when the mold is full—or to blind them.

59. The correct escape of gas is through the sand, which is either naturally or artificially vented.

SUMMARY

60. The above summarizes the methods at the disposal of foundrymen in meeting the conditions enumerated for obtaining sound castings. In experimenting with them, they can get this result at a minimum cost. It probably will be interesting for our colleagues to select a few examples for experimentation.

61. The writer shows, in the succeeding paragraphs, his first point of view and also his actual ideas, which are based on several years' experiments of a certain few cases.

Semi-Steel Shells Made During War

62. In making these shells we used a down gate of small section giving slow pouring. When pouring was finished, the temperature of the metal was about the same throughout, so that it approached Condition 2, Paragraph 18, of a uniform-temperature mass. An enormous number of these shells were made during the World war by this process.

63. The bottom of the shell at the top of the mold was perfectly sound. When pouring with extra hot metal, a slight flattening was observed there, but soundness still was satisfactory (Fig. 11).

64. If the author had to do this work again, he would increase the section of runner and gate so as to keep them liquid after setting of the shell, and would obtain slow pouring through a filter core. This filter core would be taken out with a little wire hook when pouring had been finished, in order to get the benefit of total runner-height pressure during solidification.

A Cylinder with a Groove Core

65. A similar case is shown, Fig. 12. It was considered very difficult to get the casting sound on account of the groove shown at the top. The writer believes that this is a very good case of "Leonard effect." It was proposed to use chills in the groove and to put a heavy feeding head on the top.

66. To try out another idea, the writer poured a casting under the following conditions: A dry-sand core, with a minimum amount of binder, was made to produce the groove and was slipped on the pattern (Fig. 13). A groove was made at the back of this core and was filled with coke breeze. The core was carefully vented up to near the groove, with vent holes leading to the coke breeze. The pouring was through a down gate and filter core at the top.

67. As above, solidification approaches uniform temperature conditions and a perfect casting was the result. If making this casting now, the writer would withdraw the filter core as soon as pouring is completed (Fig. 13).

Wheel-Press Hydraulic Cylinder

68. The sketch, Fig. 14, represents a wheel-press hydraulic cylinder made at the old Western Railway Works, France, by Mr. Saillot, who initiated the writer in foundry trade. The cylinder weighs five to six tons and is poured by a down gate

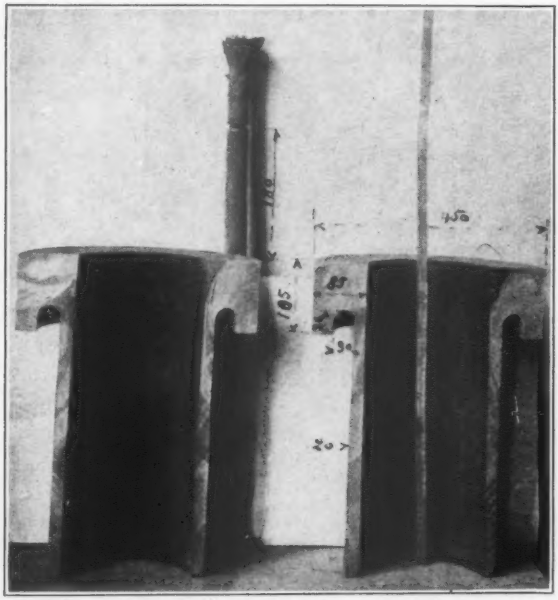

FIG. 12—CYLINDER WITH A GROOVE CORE.

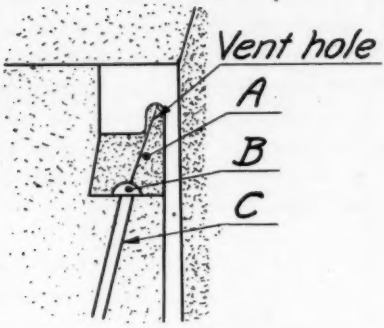

FIG. 13—METHOD OF CORING AND GATING CYLINDER WITH GROOVE CORE (FIG. 12), WITH SATISFACTORY RESULTS. *A:* DRY-SAND CORE. *B:* GROOVE FILLED WITH COKE BREEZE. *C:* VENTING HOLES.

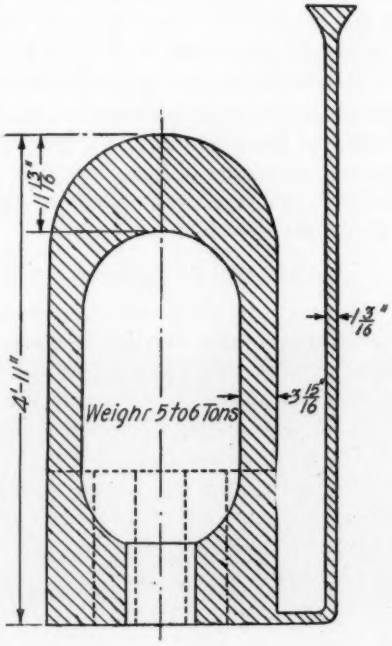

FIG. 14—WHEEL-PRESS HYDRAULIC CYLINDER POURED THROUGH SINGLE SMALL GATE AT BOTTOM WITH NO RISER ON THE TOP.

of small section without feeding heads or risers. Two of these cylinders have been poured which are still in use.

69. The case is somewhat different from the previous example because trouble might be met because the bottom part of the casting, being fed with metal up to the last minute, might show shrinkage cavities. It may be said, however, that this metal is colder at the end of pouring than that which has filled the top part, and that uniform cooling of the mass still is approached.

70. The first of the two cylinders was poured with a little larger runner and showed a small flattening at the top, but it was put into service and did not leak. The second one, poured with a 3/16 in. sprue, showed no flat.

71. It is impossible to say if there were any drawn parts anywhere, as the castings are always in use. The author would now suggest (a) a much larger sprue of a dimension approaching the section of the casting thickness near the gate, (b) pouring at the same speed as with above sprue and (c) regulating the pouring speed with a core or the equivalent near the basin.

72. Most castings of this character are lost through imperfect core venting, the gas escaping for a long time through the metal and causing porosities. Here the slow pouring has a beneficial core-burning action. The shape of the mold is such that there is no danger of scabbing.

Hydraulic Cylinder

73. Fig. 15 shows a different case of Condition 3, Paragraph 13—i. e., the cooling through parallel layers. This hydraulic cylinder was cast at Esperance Longdoz Works, Liege, Belgium, by Mr. Varlet, who is well known in foundry circles. Its weight is approximately 10 tons and it is poured through eight $\frac{5}{8}$ in. diameter gates from a top basin.

74. To insure soundness and for safety reasons, a feeding head has been provided; but this head is perfectly sound (as may be seen from Fig. 16), as is the cylinder itself (Fig. 17). The riser could have been dispensed with.

Ingot Molds

75. A few years ago the author suggested to a firm in Middlesbrough, England, to pour 10-ton ingot molds by a similar

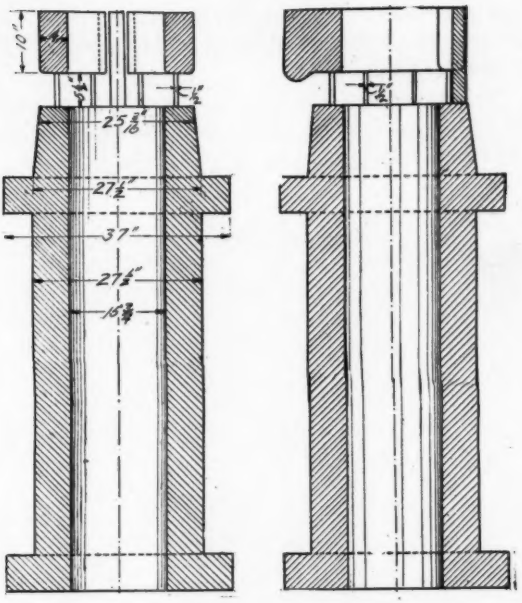

FIG. 15—SECTIONS OF 10-TON HYDRAULIC CYLINDER POURED THROUGH EIGHT ⅝-INCH DIAMETER GATES.

FIG. 16—FEEDING HEAD PROVIDED IN POURING 10-TON HYDRAULIC CYLINDER (FIG. 15), SHOWING SOUND STRUCTURE.

process to the above. They tried five 5/8 in. round gates and have now poured thousands of ingot molds this way. They say they are heavier than before.

76. This process of solidification is similar to what is used for brass slab ingots, which are poured in ingot molds through a fixed number of calibrated holes of a metallic basin (Fig. 18).

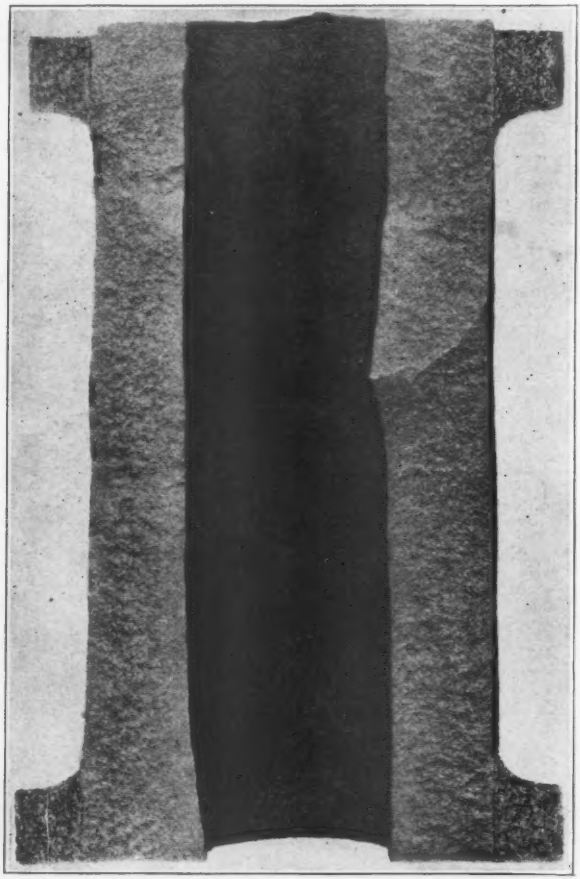

FIG. 17—SOUND METAL OF HYDRAULIC CYLINDER (FIG. 15), PROVIDED WITH FEEDING HEAD (FIG. 16) WHEN POURED.

Coupling

77. Fig. 19 shows an interesting case, a coupling, a kind of casting which is frequently met. An English friend of the author having seen some castings poured at the author's foundry —the pouring being through the core with small gates—tried and succeeded in getting a sound casting.

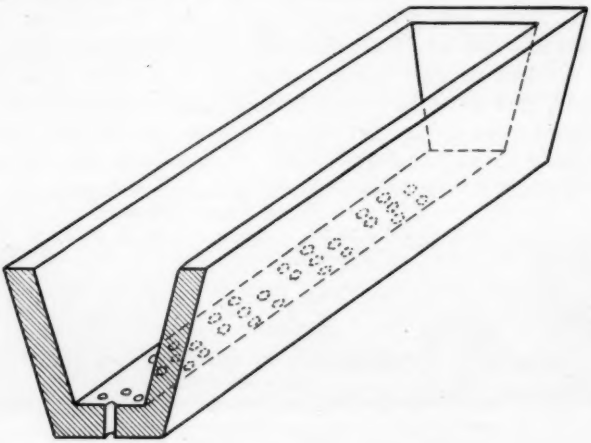

Fig. 18—Pouring Basin for Brass Ingots. Pouring Is Through Calibrated Holes in the Base.

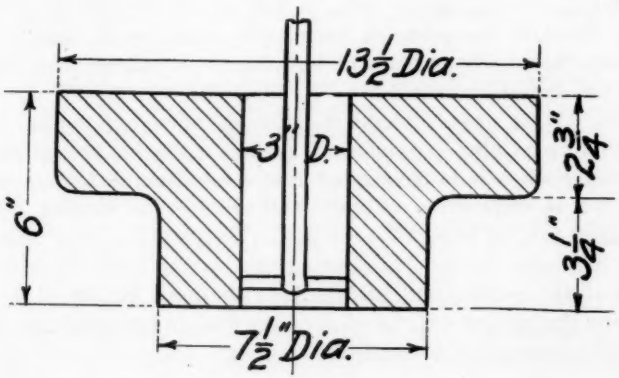

Fig. 19—Coupling Poured Satisfactorily Through the Core with Small Gates. (See Fig. 20.)

78. The author believes that in this case it came under Condition 2, Paragraph 13—i. e., uniform cooling with cold-poured metal. He made himself similar work by a process utilizing parallel-layers cooling (Condition 3, Paragraph 13—Fig. 20). The runner was 1¼ in. diameter, and a filter core shown in front of Fig. 20 was used. In using a large enough runner, it can be considered as a feeding head.

79. When separate feeding heads are resorted to, well-known rules must be followed, for instance, those recalled in R. R. Clarke's paper.[13] This corresponds to Condition 4, Paragraph 13, and must be liberally employed when quick pouring is indispensable, as in that case advantage cannot be taken of progressive or mass solidification. It is useless here to enter into details of this process which is familiar to foundrymen.

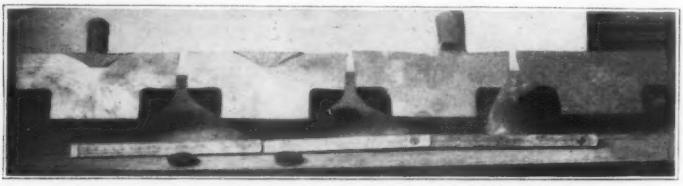

FIG. 20—COUPLINGS POURED BY PROCESS OF PARALLEL-LAYERS COOLING, WITH 1¼-INCH DIAMETER RUNNER AND FILTER CONE.

80. The writer also wishes to call attention to the fact that the points he has mentioned are not special to cast iron. In fact, the first observations have been made by E. Saillot in railway bronze,[14] and many satisfactory results have been obtained in this material.

81. It is more difficult to succeed when high-liquid contraction materials are considered, such as malleable or cast steel, especially when it is considered that a good many foundrymen consider it imperative to use down gating for casting steel. Whether this is imperative or not, a reduction of the feeding head has been obtained in pouring the casting with the feeding head at the bottom and gating there by down gating, then by turning the casting over as soon as the runner has solidified and finishing eventually by artificial cooling.

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[13] R. R. Clarke, *Risers, Their Need and Feed.* TRANS., Amer. Fdymen.'s Assn., vol. 36 (1928), p. 419.

[14] E. V. Ronceray, *Castings Made Without Heads. The Foundry,* Oct. 15, 1922, pp. 828-832.

Stronger Aluminum Castings by Improved Foundry Practice

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Abstract

This paper discusses those factors of aluminum founding which must be studied carefully in order to get the best qualities in aluminum castings. Variables in foundry practice which affect the strength of castings and which are reviewed in detail are: (1) Melting of metal; (2) Pouring temperatures; (3) degree of chill imparted to the metal by kind and temper of sand; (4) path taken by metal through the mold after leaving the gates, and (5) rate of solidification in the various sections of the castings. An investigation was carried out which showed that test bars attached to castings did not give the correct information regarding the actual properties of the castings. Radiographic examination of castings provides a valuable means of improving foundry methods to secure better castings. Pattern design should be studied, as changes often can be made to improve soundness and strength. Frequently pattern design for other metals should be changed when to be poured of aluminum. A study of core design also is important. Careful control of molding sand properties is advocated, as an ideal sand for aluminum is one which combines high permeability, compressive strength, durability and fine texture. Low permeabilities and low green strength are the cause of many failures. Gating, use of chills and risers all affect shrinkage, cracking and hot shortness. Care must be exercised to prevent contamination of the metal in melting, and to secure proper pouring temperatures and pouring heights.

1. Every casting has certain functions to perform. To do this satisfactorily it must be strong enough for the purpose for which it is intended, and from an economical standpoint it must be as light in weight as its use will permit.

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2. Certain sections of castings are stressed less highly than others. These sections may be made with thinner walls and less reinforcing ribs, provided the foundry will co-operate with the designer. By so doing, foundrymen can acquaint themselves with the functions of every casting and control the various foundry variables in such a way that the strongest metal is in the section of the casting receiving the maximum strains in service.

3. For example, five castings made from the same pattern can be made in as many different ways in the foundry and all will present the same surface appearance upon completion. However, on being subjected to physical tests approximating actual conditions, and X-ray examination, no two of the five castings will show the same properties.

4. Which practice, then, should be followed in making these castings so that they will meet the design stresses, and how is the designer to know that his design is correct? It is the purpose of this paper to discuss in general just these things—methods of testing aluminum-alloy castings, and the effect of foundry variables on the strength and soundness of such castings.

METHODS OF DETERMINING STRENGTH TO GIVE BASIS FOR IMPROVING PRACTICE

5. It is quite necessary, in order to determine the effect of the various foundry variables upon the strength of any particular casting, to find some accurate method of comparing their effect upon the physical properties. Several methods have been developed for determining the physical properties of castings, each of which has been considered in this connection, which are as follows:

(1) By making tensile tests on individually-cast test bars.

(2) By making tensile tests on test bars attached to the casting.

(3) By making tensile tests on test bars machined from various sections of the casting.

(4) By making breakdown tests on the casting as a whole.

6. It is apparent that, with the exception of the last method, the methods must be taken collectively in order to draw correct conclusions regarding the casting as a unit.

Variables in Practice Which Affect Strength

7. Before considering these methods individually, it is well to consider the general variables in foundry practice which affect the strength of a casting. These may be enumerated as follows:

(1) The melting of the metal.

(2) The pouring temperature of the metal.

(3) The degree of chill imparted to the metal by the kind and temper of the sand.

(4) The path taken by the metal through the mold after leaving the gates.

(5) The rate of solidification in the various sections of the casting.

8. Ideal casting conditions are attained when the above variables are so regulated as to give the highest possible physical properties in the castings themselves.

Individually-Cast Test Bars

9. In the case of individually-cast test bars or castings of simple design, the regulation of the aforementioned variables is relatively simple, and the studies made as to the effect of these variables on test bars are invaluable if the improvements in test-bar practice are applied to the castings themselves. However, in the case of the more intricate castings, the control of these variables is a more difficult matter.

10. Individually-cast test bars, made in a standard green-sand mold without artificially chilling and under the same ideal conditions from day to day, can give the foundryman an accurate means of determining only whether the metal is, first, within the chemical specification for the particular alloy; second, properly melted; and third (in the case of heat-treated alloys), properly heat treated. Although individually-cast test bars do not show the strength existing in the castings themselves, nevertheless, by knowing the physical properties of such test bars certain conclusions can be made regarding the properties of the casting which they represent.

11. Comparisons over a period of years indicate that test bars cut from castings made from the same metal and with proper foundry technique will have a minimum tensile strength of at least 70 to 75 per cent of that obtained on the individually-cast test bars. This relation between the tensile strength of individually-cast test bars and castings themselves has been

obtained through numerous experiments in which test bars were machined directly from the casting for comparison.

THE ATTACHED TEST COUPON

12. It frequently is assumed that test bars or coupons attached to a casting are a means of determining casting strengths, and there still are some engineers who insist on their use. In many cases, to insure high strength in the attached test coupon by proper pouring and rate of solidification, strength must be sacrificed in the sections of the casting adjacent to the test coupon, because of the resulting draws or strains in those sections. Likewise, to insure high strength in the casting often means sacrificing strength in the attached test coupon.

13. A consideration of the foundry technique connected with any particular casting will readily show why the above facts are true. Castings with light and heavy sections require the proper placing of gates, risers and chills to insure the uniform, rapid, progressive solidification necessary for maximum properties. The lightest section, farthest removed from the gates, governs the pouring temperature of the casting and may be considerably higher; or, in the case of heavy castings, it may be lower than the pouring temperature desired for maximum properties of individually-cast test bars.

14. This does not necessarily mean that the metal entering the various parts of the casting pattern cavity is either hotter or colder than the correct test-bar temperature. The temperature of the molten metal as it fills various sections of the casting depends entirely upon the location of these sections with respect to the gates, and can be controlled to some extent by means of properly placed chills and the path of the metal over the sand walls of the mold or cores in reaching its final resting place.

15. However, the temperature of the metal entering the attached test-coupon pattern cannot be so readily controlled. If this cavity is near the gates, the metal temperature will be higher than if it were removed from the gates, and the physical properties will vary accordingly.

TEST BARS MACHINED FROM CASTINGS

16. In order to obtain the true strength of the various sections of a casting, test bars should be machined from these sections and tests made. In this way the weak sections can be

determined and the necessary corrections in the foundry technique made to correct them.

17. This method of determining the strength of a casting is especially important in the development of the casting technique, for by properly placing the gates, risers and chills, the sections of the casting which receive the greatest stress in service can be made the strongest.

Breakdown Tests

18. Although the tests of bars machined from the various sections of a casting may be useful in developing foundry technique, it is quite an advantage to make a proof load or breakdown test on the casting as a whole to prove out the design.

19. By so arranging these breakdown tests to approximate the conditions the casting actually will have to meet in service, valuable data can be obtained for the designing engineer. In some cases these conditions can be determined by the nature of the casting, while in others the designing engineer should supply the direction and loading of the stresses which have to be met.

20. After once determining the best foundry technique to produce the proper strength in the heavily stressed section of the casting proper, foundry control can be maintained by periodically repeating the breakdown tests.

21. Such tests as these give the manufacturer as well as the purchaser a far better working conception of the strength of the casting, than the knowledge of either the strength of the individually-cast test bars, attached test coupons or bars cut from castings. They also afford a means of developing castings in aluminum of sufficient strength to replace various castings now made in other metals.

Comparison of Methods of Testing

22. To show the relation between the properties of a casting as obtained by the several methods of testing, a typical case is shown in Fig. 1. This is a relatively simple casting, inasmuch as it is free from cores and intricate design features.

23. Table 1 gives the properties as obtained from separately cast test bars, attached test coupons, test bars machined from various sections of the casting and a breakdown test on the casting as a whole.

24. Two castings were made with slightly different foundry

technique. In casting No. 1, the technique was developed to give maximum strength to the casting. The technique employed with casting No. 2 gave maximum properties to the attached test coupon but inferior properties in the casting.

25. Examination of the results show that the best casting, from a designer's standpoint, is not the one having the best results for the attached test coupon, in that both the average strengths of the bars machined from the casting and the breakdown load on the casting as a whole show the opposite results.

RADIOGRAPHIC EXAMINATION OF CASTINGS

26. Since the external appearance of a casting is often misleading as to its internal soundness and hence its strength, it is quite desirable to investigate this condition in the development of casting technique. Radiographic examination by means of

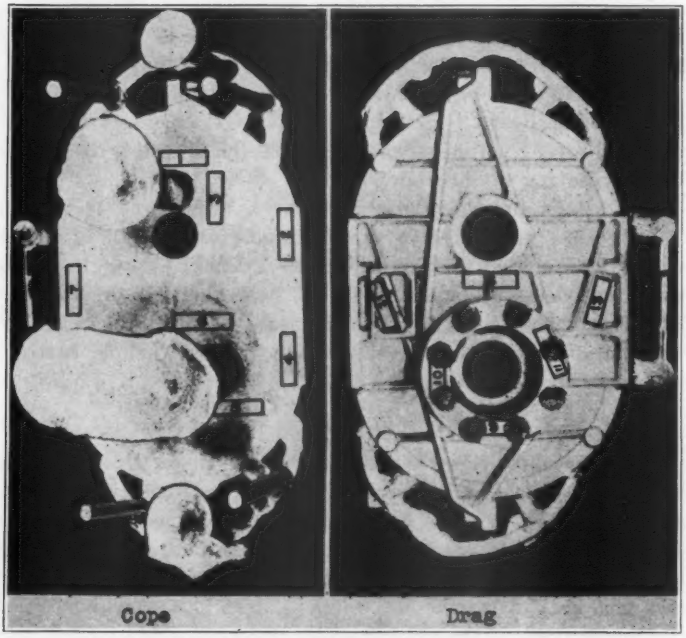

FIG. 1—END PLATE FOR AIRPLANE ENGINE SUPERCHARGER, SHOWING TEST-BAR LOCATIONS WITH REFERENCE TO GATES, RISERS AND CHILLS—CHILL LOCATIONS DARKENED. (SEE TABLE 1.)

X-ray photographs affords an excellent aid in this respect. Internal defects such as shrinks, dross, porosity, inclusions, blowholes, and the like, can more readily be disclosed by employing X-rays than by the usual methods of machining or fracturing.

27. Radiographic examination is particularly valuable in determining the soundness of highly stressed sections. These may be individual castings or merely the vital sections of large fabricated units.

28. Since an examination of this sort does not destroy or affect the casting in any way, it is quite adaptable as a means of inspection. In some instances it has been found advisable to X-ray all of a certain lot of castings, while in other cases a frequent check on castings taken at random from routine production is sufficient.

Radiography Valuable in Developing Methods

29. The chief value of radiography in the foundry is during the development of the foundry technique to be used in the

Table 1

SUMMARY OF RESULTS OF PHYSICAL TESTS ON END PLATE FOR SUPERCHARGER

Bars cut from castings location.	Casting No. 1			Casting No. 2		
	Tensile strength, lbs. per sq. in.	Elongation, per cent in 2 in.	Brinell hardness.	Tensile strength, lbs. per sq. in.	Elongation, per cent in 2 in.	Brinell hardness.
1	32,900	2.70	72	28,900	2.70	62
2	28,600	2.70	68	31,400	8.00	65
3	31,400	4.00	72	31,400	4.00	62
4	28,600	4.00	72	26,500	5.50	59
5	28,600	4.00	72	27,500	5.50	65
6	28,600	2.70	72	26,700	2.70	62
7	43,250	6.70	65	28,900	4.00	62
8	41,500	8.70	65	32,850	12.00	62
9	27,500	4.00	68	33,400	10.70	65
10	33,200	5.40	62	28,600	4.00	59
11	33,800	6.70	59	31,100	2.70	65
Maximum	43,250	8.70	72	33,400	12.00	65
Average	32,450	4.70	68	29,750	5.60	63
Minimum	27,500	2.70	59	26,500	2.70	59
Individually—cast test bars	29,800	9.00	66	32,100	8.00	66
Attached test coupon	24,650	5.00	65	30,450	6.00	61
Breakdown test, failure in lbs..	.....	8,090	..	.....	7,110	..

routine production of castings. When used in conjunction with the various methods of determining the physical properties of a casting, radiography affords a relatively rapid means of fixing the foundry variables.

30. It is the practice to X-ray the first few castings from every new pattern while making the changes that seem desirable for increasing the soundness of the casting. A study of the radiographs will aid in telling whether the gates are properly placed, the effect of chills and risers on the porosity and the presence of undesirable inclusions in the casting.

31. This examination, correlated with the physical tests

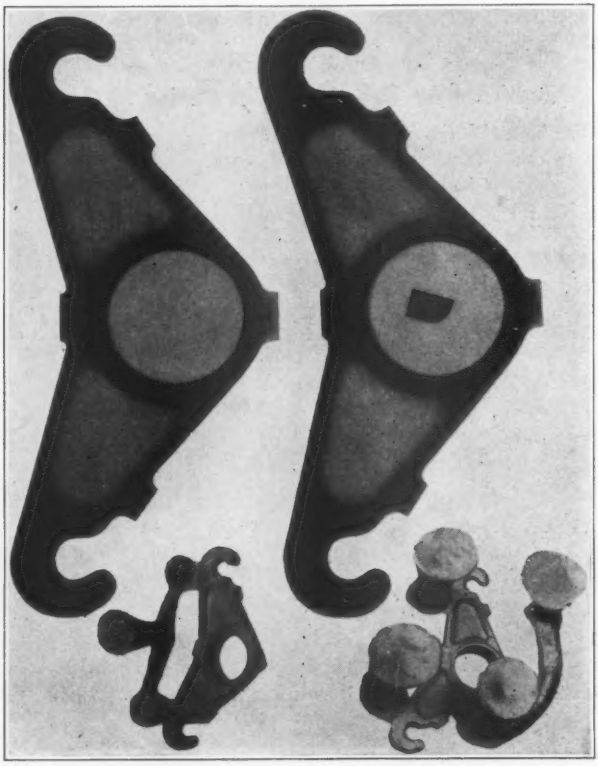

FIG. 2—RADIOGRAPHS SHOWING VARIATION IN POROSITY DUE TO METHOD OF GATING. LEFT — ORIGINAL CASTING. RIGHT — RESULTS POSSIBLE THROUGH CHANGE IN GATING.

made at the same time on the castings, gives the necessary information for improving the strength of any casting. Once a definite foundry technique has been established and the pattern is placed in routine production, the X-ray generally is used only for occasional checks.

32. One of the numerous examples of the use of the X-ray for casting development is shown in Fig. 2. This shows the original and final method of gating a relatively simple casting, together with representative radiographs. The change in the gating of this particular casting resulted in a 50 per cent increase in the casting strength as determined by a breakdown test.

PATTERN DESIGN

33. From the foregoing discussion it is evident that strength and uniformity in castings are closely dependent not on test bars—either individually cast or attached to the casting—but upon the proper correlation of foundry technique with the design of the casting. Some of the controllable variables in foundry technique are described in somewhat more detail hereafter.

34. All castings are designed with the idea of their answering a certain purpose or performing a given function. These principal functions of necessity must remain foremost in mind in the construction of the pattern for each particular casting.

35. This does not necessarily mean that only one design will fit each job, and it is not the purpose of this discussion to advocate any particular design for aluminum alloy castings. It is desired, however, to bring out several design features whose use will facilitate in the production of stronger aluminum-alloy castings.

Factors to Overcome Shrinkage and Hot Shortness

36. It is a well-known fact that aluminum alloys have rather marked shrinkage and hot shortness characteristics, dependent to some extent on the type of alloy. Any design feature which, incorporated in pattern construction, tends to minimize the effects of these inherent properties will be well worth consideration.

37. Under such features can be classed the following:

(1) Generous fillets at all angles aid materially in reducing

shrinkage and cracks at these points. The improper use of chills at these points many times apparently corrects the shrinkage on the surface but promotes columnar grain structure and develops a tendency toward cracks and internal shrinkage.

(2) In gated patterns, match plates, cope and drag equipment, or any other patterns in which the gates and risers are fixed in the pattern shop, care should be taken that the metal does not enter the casting through those sections which may become heavily stressed in service. Of course, the best locations can be more accurately determined before they are fixed for production, by means of physical tests in connection with casting characteristics. Such tests should include a breakdown test and determination of physical properties of test bars machined from the castings.

(3) The avoidance of abrupt changes in the wall thicknesses of castings decreases to a considerable extent the tendency to shrinks and cracks. When such conditions are necessary, provisions should be made to feed the heavy section by means of risers directly connected to them. Feeding is not satisfactory through thin sections into heavy sections.

(4) Thin ribs and fins should be given considerable thought. In many cases, because of their rather rapid cooling, they may set up strains in the heavier sections of a casting, with the ultimate result that cracks may occur during heat treatment, machining or assembly. Sometimes these cracks may occur in such remote sections that their cause at first cannot be connected with a rib. It is well worth while to check this condition whenever cracks are experienced.

(5) Whenever possible, machined surfaces should be cast in the drag to eliminate as much as possible the presence of dross and porosity often present on the cope face. If a machined surface is made in the cope, additional finish should be allowed on the pattern to permit machining down to sound metal.

Core Design Factors

38. It is quite desirable that all of the above points be incorporated in core design also, as well as in pattern design. In addition, the following items should be considered.

(1) Core prints of sufficient size—not only to give a suitable support for the core, but to permit easy escape of core gases—should be employed. This is particularly important in cores

completely surrounded by metal, where insufficient means of escape for the core gas developed in the mold may cause porosity and blow holes.

(2) It is very desirable to vent all cores to permit easy escape of the gases generated on the interior of a core. Entrapped core gas often induces excessive porosity and is not desirable, at least in thin sections subjected to pressure requirements.

Pattern Equipment Designed for Other Metals Modified for Aluminum

39. Patterns and pattern equipment formerly used for brass, bronze, cast iron and malleable iron often must be remodeled before they can be used satisfactorily for aluminum alloys. The necessary changes will vary with the particular casting and in general will result in increased sections and change of gating.

40. Patterns used to produce pressure-tight castings in ferrous and nonferrous metals often will require increased wall thickness when used with aluminum alloys. Aluminum alloy castings, to have strength equal to castings in these other alloys, often will have to have somewhat increased sections.

41. Just what increase in section is necessary is difficult to state, since this will depend upon the utility of each casting. However, the determination of these figures is made relatively simple through the use of breakdown tests upon the casting as a whole, in conjunction with the necessary pattern changes.

Case of Alloy Seat Bracket

42. Fig. 3 shows the various steps used in the development of a heat-treated, aluminum-alloy seat-bracket casting to be used to replace castings formerly made of malleable iron. The casting at the extreme left was made from the original malleable iron pattern and subjected to comparative breakdown tests to determine the points at which the failure occurred, so that section changes could be made on the pattern.

43. Since this particular casting is subjected to considerable impact as well as dead load, the tests were arranged to compare both these properties with those of the malleable iron. Intermediate changes in pattern design were made with wax on the original malleable-iron pattern, and castings were made for

tests from each change until a suitable design was developed which gave castings of equal or better physical properties than those of malleable iron.

44. Table 2 gives the condensed test data as well as the weights of the various castings. When the final design is determined, permanent changes are made on the pattern and production of castings can be started.

MOLDING SAND

45. Sand control in the aluminum foundry is an important factor in the production of good castings. Permeability, cohesiveness (as measured by compressive strength) and durability are among the properties of molding sand which determine its usefulness.

46. These, together with moisture content, should be checked and controlled by routine tests. The effects of variations in the properties of molding sand upon the strength and quality of castings should be thoroughly understood and recognized.

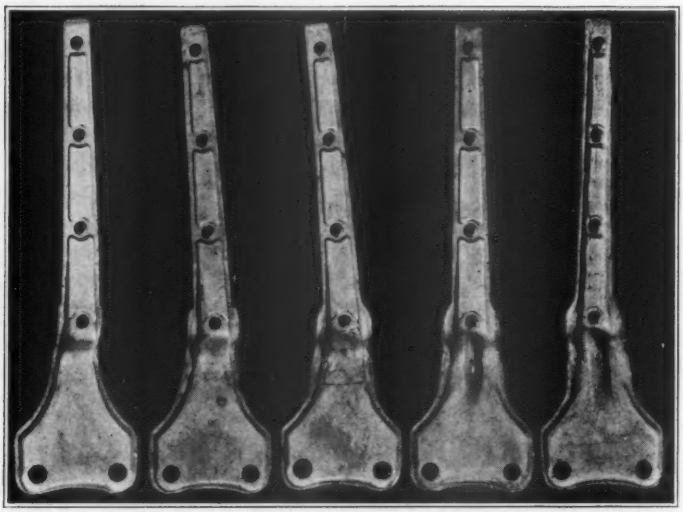

FIG. 3—HEAT-TREATED ALUMINUM-ALLOY SEAT BRACKET, SHOWING STEPS IN PATTERN DEVELOPMENT TO OBTAIN SAME STRENGTH AS WITH MALLEABLE-IRON CASTING.

An Ideal Sand for Aluminum Casting

47. An ideal molding sand for aluminum alloys is one which combines high permeability, compressive strength, durability and fine texture. Such a sand cannot be realized, since the great mobility and sand-searching power of aluminum alloys require the use of sands of fine grain. Sand penetration is therefore prevented by sacrificing permeability in the finished mold.

Low Permeability Cause of Many Defects

48. Low permeability of the sand in a mold prevents the complete escape, through the sand, of gases and steam generated when the molten metal comes in contact with the sand. This often results in blow holes within the casting, or shallow depressions known as hard ram blows on the surface of the casting. Shrinkage on thin and more or less flat castings often can be traced to localized areas of low permeability.

49. Apart from the original character of the sand, low permeability in a mold may be the result of hard ramming, uneven ramming and high moisture content of the sand. Hard ramming has the effect of closing the pores in the sand, which action prevents the ready escape of gases and steam and results in blow holes and hard ram blows.

50. In addition to its association with blows, low permeability resulting from hard ramming in certain areas may be the cause of a certain type of surface shrinkage which often is attributed to poor quality of metal. This type of shrinkage

Table 2

STATIC BREAKDOWN TEST DATA—MALLEABLE-IRON AND ALUMINUM-ALLOY SEAT BRACKETS

Casting No.*	Alloy.	Weight, lbs.	Static Test		Section† increase, per cent.
			Maximum load, lbs.	Maximum def., inches.	
Original	Mall. Iron	2.90	510	2.55	0.0
1	195 HTT**	0.90	255	1.53	0.0
2	195 HTT**	0.99	390	1.35	8.0
3	195 HTT**	1.06	505	2.00	36.0
4	195 HTT**	1.10	515	2.50	65.0
5	195 HTT**	1.20	720	1.95	70.0
5	197 HTT**	1.15	935	6.32	70.0

*Casting numbers refer to pattern changes in Fig. 2.

**Aluminum Company of America aluminum-alloy number.

†Per cent increase in cross section of casting at point of failure over the original cross-section of malleable-iron casting.

often occurs on thin flat sections and is due to an insulating layer of gas which retards the speed of solidification.

51. This condition has the effect of creating an area which solidifies later than the surrounding areas and is therefore isolated from the source of feeding metal. The result is an area of inter-granular shrinkage which becomes prominent because of a larger grain size induced by the slower speed of solidification. In such instances, hard ramming has resulted in the production of a casting containing areas of unsoundness and decreased strength.

52. Other factors which contribute to low permeability are high moisture content and the presence of too much fine material in the sand. Both of these factors tend to make the sand pack more tightly under ramming, thereby closing the pores in the sand. Under the head of fines are classed clay bond and particles caused by disintegration of the sand after repeated use.

Green-Sand Strength

53. Low green-sand strength of molds is responsible for a considerable amount of casting defects, such as cope drops, sand washes and core crushes. The sand in a mold must have sufficient strength to resist the washing action of the molten metal, to support set-in cores and to withstand jars and knocks to which molds are subjected in handling. These stresses usually are in compression, and the strength of the sand usually is measured by its resistance to failure by compression.

54. This laboratory test is quite simple and gives fairly consistent results. The usual method is to determine the lower limit of compressive strength of the sand to be used which will give satisfactory results in the foundry and maintain the strength above this limit.

55. Compressive strength tests are not always an accurate measure of the worth of the sand. A high moisture content in sand which is well "burnt out" will often give good strength when tested but will result in cope drops and washes in the foundry. A good sand is one which can be worked dry without losing much of its cohesiveness.

56. The strength or cohesiveness of the sand is determined largely by the kind and amount of bonding material and the moisture content of the sand when ready for use. This necessitates first the selection of a sand with a desirable degree of

permeability and strength. These properties then must be maintained in the foundry by controlling the moisture content and adding new sand or some artificial binder to maintain the proper strength compatible with permeability.

Cores

57. The use of cores in aluminum-alloy castings presents a number of problems which greatly affect the production of good castings. In general, a core should have sufficient strength to be handled without excessive breakage, and should withstand the strains induced by metal pressure in the mold.

58. Cores which are surrounded by molten metal must have a high permeability in order to permit easy escape of the relatively large volumes of core gas generated. Cores have a natural high permeability, due to the coarseness of the sands generally employed; but this should be augmented by venting cores as much as possible. This practice will do much toward eliminating blows and porosity in castings.

59. It is known that aluminum alloys have a large linear contraction and are hot short. Hence, it is essential that cores in thin-walled castings be soft and easily crushed by the casting when it contracts. If the core is too strong or hard, a crack invariably will develop.

Mixtures Depend on Core Requirements

60. Many varieties of sands and sand mixtures are employed for cores, depending upon the source of supply and the class of work. Lake sands and local bank sands find wide use in core-sand mixtures.

61. There are a number of binders used, depending also upon the kind of core desired. Core oils with linseed oil bases are generally used for ordinary work. Resin often is used as a binder, but it will harden if the casting is allowed to cool before it is knocked out. Binders which give off an excessive amount of gas when in contact with molten metal should be avoided.

62. The important thing about core sand mixtures is that they should be made up according to the requirements of the cores. Body and housing cores should be soft. Ram-up cores should be hard. Jacket cores should be permeable.

63. Therefore, core sands, and particularly binders, both kind and quantity, and moisture content must be controlled

closely to obtain the best castings. For example, the strength of cores made with certain corn-compound binders increases rapidly with increased moisture content in the sand mixture, as shown in Fig. 4.

GATING

64. Improper foundry practice often is responsible for casting defects such as shrinkage and cracks. These defects are easily visible when they are external, but only X-ray examination or fracture will reveal these defects when they are internal. Cracks sometimes are so fine that only the severe quench of the heat-treating operation will expose them.

65. Many of these casting troubles originate in the character of the metal, namely, high shrinkage at solidification, large coefficient of contraction and hot shortness. Since these properties are inherent in aluminum, their effect upon castings can be minimized only by proper foundry practice, such as gating and use of risers and chills.

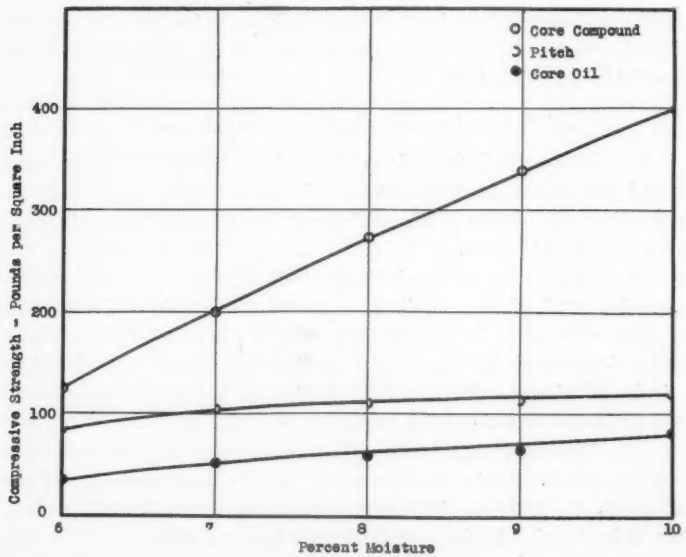

FIG. 4—EFFECT OF MOISTURE ON COMPRESSIVE STRENGTH OF CORES MADE WITH VARIOUS COMMERCIAL BINDERS.

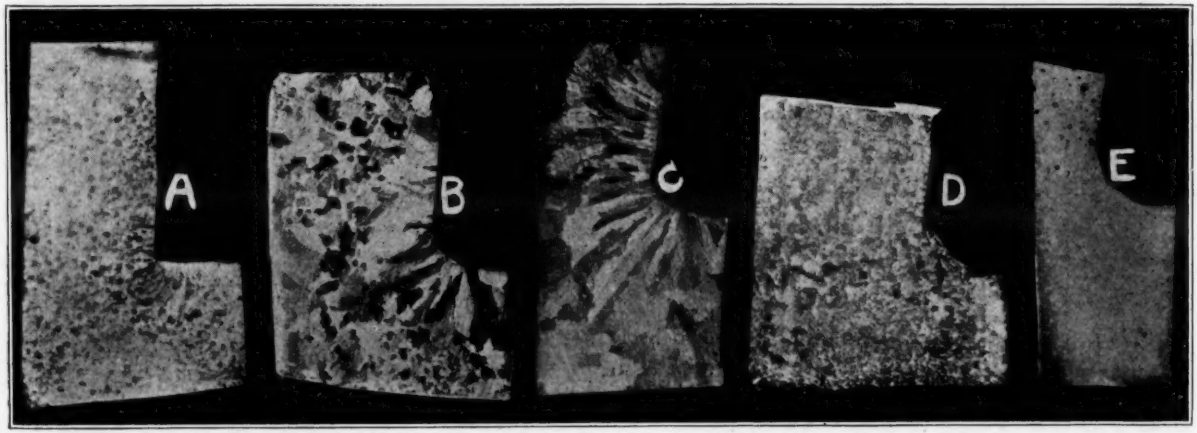

Fig. 5—Effect of Various Methods of Chilling on Grain Structure of Angles Formed by a Heavy and and Light Section.

A: Angle as Designed Without Fillet. Cracks Occurred at Corner Even When Chilled.

B: Same as *A*, With Fillet and Chill in Corner. Note Elongated Grains Due to Chilling. This Type of Structure Is Very Susceptible to Cracks.

C: Same as *B*, After Heat Treatment, Showing That Structure Remains the Same.

D: Original Section With Fillet But Without Chills. Cracks Still Occurred, Due to Non-Uniform Cooling of Light and Heavy Sections.

E: Filleted Section With Chill on Outside of Heavy Section Only. Note Uniformly Fine Grain, Resulting in Elimination of Cracks.

Ideal Cooling Condition

66. The ideal cooling condition for sound castings is a uniform, rapid, progressive solidification proceeding from points furthest from the gates toward the gated area. Such progressive cooling should be worked out for each particular type of casting so that the metal as it solidifies and shrinks is fed by molten metal immediately adjacent. This condition is obtained by proper gating and the careful use of risers and chills.

67. Internal shrinkage, which indicates primarily a lack of feeding, usually occurs in heavy sections, such as lugs or bosses, and in junctions between heavy and light sections. Risers at such points usually will correct the trouble. Shrinkage may be overcome also by gating into the thin sections, thereby delivering colder metal to the heavier sections.

Chills Advisable Under Certain Conditions

68. It is often advisable to employ chills in order to hasten solidification in certain parts of a casting. Such practice may be necessary to obtain the ideal, uniform, progressive rate of solidification.

69. Chills also are used when a hard surface is desired. It often is necessary to use risers when the chilled sections are very heavy.

70. Over-chilling must be guarded against because it may produce a columnar grain structure which may weaken the casting to the point of cracking. The proper placing of chills also is important (Fig. 5). They should not be placed so that they affect the structure of adjoining thinner sections.

71. The method used to overcome internal shrinkage will depend somewhat on molding and trimming considerations, as well as on the type of casting. For heavy castings, a combination of chills and risers is commonly used. In small castings, chills or risers may be used.

72. Chills are preferable unless the shrinkage occurs at a point difficult to chill, such as the cope side of a cored casting. In such instances, risers should be used even though they cause more trouble in the trimming room.

Cracking Largely Due to Hot Shortness

73. Cracking in aluminum-alloy castings is due largely to hot shortness at temperatures slightly below the solidification

temperature in conjunction with natural lineal contraction. There are, of course, a number of immediate causes for cracks. Of these, a difference in degree of solidification in various parts of the casting is, perhaps, the most important.

74. For example, one part of the casting will be solid and begin to contract, while an adjacent section still is soft. This latter section will be unable to resist the contraction stresses set up, and a crack will result. The presence of dross or porosity in such sections will accentuate the tendency to crack.

75. The remedy for cracking, then, is to hasten solidification in the weak sections by the use of chills or by rearrangement of gating to deliver colder metal to these points.

Risers Influence Cracking

76. The use of risers has an important influence upon cracking. A riser may be needed at a certain point to eliminate internal shrinkage where such shrinkage may be responsible for a crack. On the other hand, the riser may be too large or entirely unnecessary. This would have the effect of keeping the section, which it is supposed to feed, molten for too long a time, and would also result in a crack.

77. Risers and sprues must not be placed too close to the cross bars in the cope flask. Otherwise there is danger that the casting will become anchored and not be free to move when it contracts, thereby causing cracks. A similar condition exists when the sand has been rammed too hard.

78. These physical influences of risers and sprues may be lessened in several ways. Besides keeping them away from the cross bars, the risers and sprues may be partially cut away from the casting while they are still soft. Wedges may be placed adjacent to them in the mold and removed as soon as possible. In some instances the mold may be lifted from the drag board to prevent the sand from offering undue resistance to contraction.

Use of Fins to Dissipate Heat

79. Dissipation of heat to promote more rapid cooling, which is one of the functions of chills, may also be accomplished by the use of fins. Small castings of fairly uniform sections, which on account of design are prone to crack, may be saved by cutting a thin fin in the mold at the weak point. This fin

will not only promote more rapid cooling but will have a strengthening effect.

80. Quite often the crack will occur in the fin but stop short of the casting. At the same time, runout fins may start rapid cooling in locations where it is not desired and cause cracks because of their chilling effect. The use of thin fins, hence, requires considerable thought and much work can still be done in this connection.

81. Aside from its effect upon internal shrinkage and cracking, gating has an important influence upon the strength of a casting. If a single gate or a few gates are employed, considerable hot metal will enter the mold at these few points, and these sections will be weak on account of the resulting coarse grain structure.

FIG. 6—ORIGINAL (LEFT) AND IMPROVED (RIGHT) METHODS OF GATING ALUMINUM-ALLOY DOUGH-MIXING-MACHINE BEATER. BREAKDOWN TEST, BREAK LOAD: ORIGINAL GATING, 2,515 LBS.; IMPROVED GATING, 3,990 LBS.

82. If these sections happen to be highly stressed in service, they may fail with disastrous results to both customer and foundry. For this reason, multiple gating should be used whenever possible to reduce gradients in metal temperature between different sections of the casting.

83. Castings should not be gated in sections subject to severe stresses in service. Fig. 6 illustrates the increase in strength experienced through a change of gating, resulting in a 60 per cent increase of strength as measured by a breakdown test.

Care of Melting and Holding Pots and Ladles

84. The necessity for proper care of melting and holding pots and pouring ladles cannot be stressed too greatly, since the effect of contamination of metal from dirty equipment of this type often is serious. Although most foundries realize the importance of clean equipment—not only with aluminum alloys but with all ferrous and nonferrous metals—there are still a few who overlook this point and very often run into difficulties, the cause of which is generally laid to faulty ingot.

85. The chemical composition limits of aluminum alloys are maintained to give certain characteristics to the alloy, among which are its physical and casting properties. To destroy the composition by the addition of foreign metallic elements picked up during melting and pouring, means that some property of the metal is being destroyed or weakened, usually resulting in subsequent foundry difficulties.

86. It is a comparatively easy matter, especially in jobbing foundries using a variety of ferrous and nonferrous alloys, to contaminate the metal either through a mixing of the scrap or by melting or pouring from equipment used previously to melt other metal and not thoroughly cleaned prior to charging the aluminum alloy.

87. It also is comparatively easy to establish a system whereby scrap from the various alloys can be kept separate and melting and pouring equipment cleaned between heats of different alloys. Such a system will aid materially toward stronger aluminum-alloy castings and less foundry difficulties.

88. Particular care must be taken in the melting of aluminum-silicon alloys, especially in iron pots, since their affinity for iron causes a rather rapid pickup of this element. Iron in excess

of certain limits affects both the physical and casting properties of these alloys, and anything that can be done to eliminate unnecessary iron pickup is to the foundrymen's advantage.

89. The best protection against iron pickup has been found to be a coating of white-wash or clay-wash on the interior of all iron melting pots and ladles, and on all other iron equipment which comes in contact with the molten metal. Such coatings should be applied at least once a day for satisfactory protection, and to all the iron equipment regardless of whether it is used in handling silicon alloys or not.

METAL TEMPERATURE

90. Aluminum alloys should be poured at as low a temperature as will fill the mold readily without causing cold shuts. It has been shown that a high pouring temperature will tend to cause unsoundness and low strength in castings.

91. Melting temperature is, of course, a function of the pouring temperature, but should be no higher than to compensate for the natural drop in temperature between the melting furnace and the mold. This is, of course, not always possible to do. On the other hand, while a pot of metal may have to be cooled 20 degs. Fahr. before pouring, there is no excuse for this being 120 degs. Fahr. instead.

92. The effect of high melting temperature is overcome only partially by allowing the metal to cool to the proper pouring temperature. Grain size, shrinkage and porosity are less when the metal is not overheated in melting. Shrinkage and porosity are affected by iron pickup, oxide formation and gas absorption, which may occur at high melting temperature. Temperature alone affects grain size, which in turn is associated with surface shrinkage.

93. For best results, metal should be used shortly after it has reached the proper melting temperature. It has been shown that soaking tends to cause the formation of a coarse grain structure and to promote surface shrinkage. In addition to this, soaking will tend to increase iron pickup in iron melting pots, as well as oxide and dross formation.

94. It has often been noticed that the top surface of an ingot poured from soaked metal will show a relatively coarser crystal structure. The shrinkage cavity often is deeper and more

spongy than if the metal were pigged without being soaked. Similar conditions exist when the metal is poured in castings as well as in ingots.

95. Control of melting and pouring temperature makes necessary pyrometric equipment for the purpose of measuring and recording temperatures. Each melting furnace should be equipped with a thermocouple. In addtion, metal temperature should be checked immediately before pouring.

96. Suitable equipment for such temperature control has been fully described elsewhere. It is essential that this equipment be kept in good condition and inspected daily if the best results are to be obtained.

Pouring Technique

97. A great many casting defects resulting in low-strength castings can be attributed to faulty pouring technique. As a rule, such defects as shrinks, cracks and blows can be eliminated by the proper gating, application of chills and sand control. Occasions arise, however, when not only these but other defects such as misruns and cold shuts can be overcome by the proper rate and steadiness of pouring at the correct pouring temperature.

98. The pouring of every casting should be so timed that the pattern cavity will fill fast enough to prevent cold shuts and misruns, and at the same time slow enough to promote uniform progressive solidification. The stream of metal entering the sprue should not be broken at any time during the pouring operation, and should enter without splashing or violent agitation.

99. The effect of pouring temperature cannot be overestimated, and accurate control after the correct temperature is determined will always result in better castings. The setting of the pouring temperature for any particular castings is best determined by actual trial.

100. Several molds can be poured with metal at different temperatures, starting with metal known to be hot enough and dropping the temperature on each successive mold until a misrun occurs. A temperature 20 degs. Fahr. higher than this lowest temperature should then be designated as the pouring temperature of the casting. The additional 20 degs. Fahr. is sufficient factor of safety to take care of the allowable variation in the temper of the sand and rate of pouring.

101. Once the pouring temperature is set by actual test it should not be changed or varied unless, of course, the method of gating the pattern is changed.

Control of Pouring Temperatures

102. It is not the purpose of this paper to go into detail as to the methods of controlling pouring temperatures, since this subject has been fully covered by previous articles. It is well to repeat, however, that guess work should be eliminated as far as possible from such control, since the temperature at which

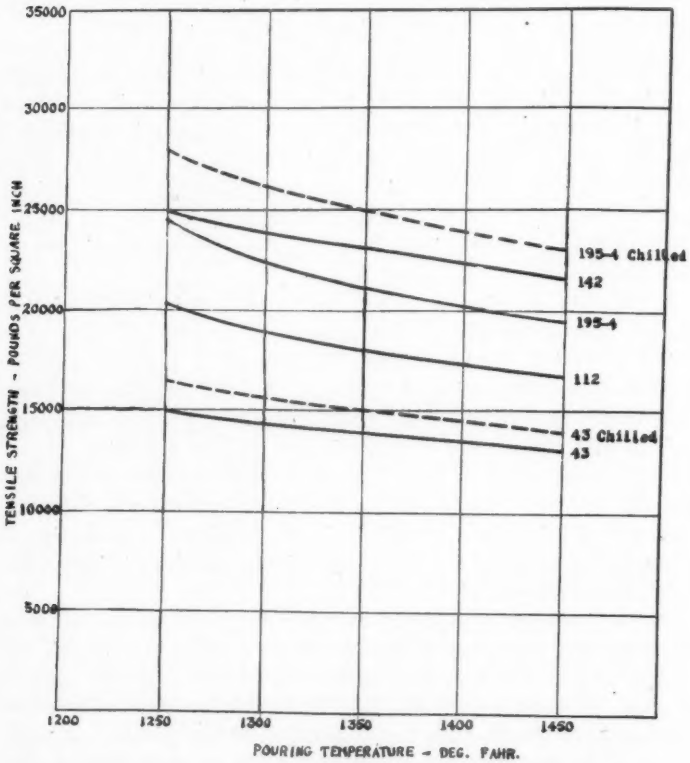

FIG. 7—EFFECT OF POURING TEMPERATURE ON TENSILE STRENGTH OF ALUMINUM-ALLOY CASTINGS. TEST SPECIMENS FROM ¾-IN. SECTIONS. MELTING TEMPERATURE 50 DEGS. FAHR. ABOVE POURING TEMPERATURE.

a casting is poured has an exceedingly great effect upon its physical properties.

103. A casting poured at the lowest possible temperature will have finer grains, less defects and higher physical properties than will the same type casting poured at any higher temperature. The effect of pouring temperature on the physical properties of test bars machined from a ¾-inch sand-cast section is clearly shown in Fig. 7.

104. After once determining the pouring temperature of a particular casting, it is quite desirable to maintain a melting temperature just enough above this to allow only for the unavoidable cooling which takes place during the handling.

105. In the smaller foundries with rather limited furnace capacity, it often is necessary—when a number of castings are being poured from one furnace—to vary this procedure somewhat and maintain the melting furnace at the temperature necessary to take care of the casting with the highest pouring temperature. For those castings requiring a lower pouring temperature, either the metal must be held in the pouring ladle until the desired temperature is reached or an accelerated cooling must be produced by some approved method.

106. Cast-iron chill rods, coated with white-wash or clay-wash, form very satisfactory cooling appliances. The addition of foundry scrap to the molten metal as a means of accelerating the cooling is to be discouraged, as it is the source of much trouble through the formation of drossy inclusions in the metal.

Skimming Immediately Prior to Pouring

metal should be very quietly and carefully skimmed to aid in preventing excessive dross entering the pattern cavity. The metal should then be poured without any further agitation or excessive splashing.

107. Directly prior to pouring, the surface of the molten

108. As mentioned before, the rate at which the pouring is done must be so timed that the pattern cavity will fill fast enough to prevent cold shuts and misruns, and at the same time slow enough to promote uniform progressive solidification. To further aid in eliminating dross, the pouring sprue should always be kept full while pouring and the stream of metal should not be broken at any time during pouring.

Height and Rate of Pouring

109. It has been found through investigation that the height of pouring, or the distance the molten metal drops from the ladle to the pattern cavity, has considerable effect upon the soundness of the resulting casting. This phase of pouring technique is not generally realized, with a result that many castings are poured without due consideration of this variable.

110. A sound casting must be free from dross inclusions and air pockets, as well as from the other foundry defects. The amount of dross within a casting is largely due to the agitation of the metal incident to the pouring of it, while trapped air is introduced into the pattern cavity through the sprue while pouring. The possibility of both these conditions becoming harmful increases with the height the molten metal falls from the ladle to the pattern cavity or the pouring height.

111. Although chokes placed in the gates and runners partially overcome the harmful effects of pouring a casting from an excessive height, they should be used only as a means of further improvement rather than as a "cure-all." Experience has shown that the soundest and, hence, the strongest castings are those poured from a low pouring height.

SHAKEOUT HANDLING

112. The control of foundry technique for the production of stronger aluminum-alloy castings does not stop with the pouring of the castings but must be carried on through the shakeout and inspection. Numerous defects, such as cracks and excessive warping, can be introduced through careless handling of the molds and castings in the shakeout process.

113. At the temperatures at which many castings are removed from the sand, their strength is rather low, and rough handling may induce incipient cracks which may or may not be discovered in the most rigid inspection. Likewise, at this relatively high temperature the casting is quite ductile and can very easily be warped out of shape by improper handling.

114. Sometimes such castings may be straightened satisfactorily when cold, but in many cases this is only possible after considerable work. It is much easier to prevent this condition by a little consideration during the shakeout than to try to remedy it when the casting is ready for shipment.

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The Value of Sales Analysis and Market Research

By J. P. Newman,* New York

Abstract

In pointing out the present trend of competition between industry and industry, the author urges the foundry industry not to become too heavily production-minded but to make production the servant of marketing. Principles of industrial merchandising are discussed and listed as: (1) Market determination, (2) buying habits, (3) channels of approach, and (4) sales appeals. One of the fundamentals of merchandising in the metal-working industry is said to be the consideration of each job in terms of parts rather than of tonnage.

1. All over the country today, manufacturers are concerned with the problems of sales. They are devoting time and energy to delving into the problems of marketing to the end that waste in distribution—one of the country's biggest losses—may at least be decreased. The Department of Commerce and the Bureau of the Census are making heroic efforts to place before American business facts and figures to aid in sales analysis, market determination and the inclusion of sales data in the budgetary control system.

2. Business today has a new tempo. It no longer can operate as it did when products were produced for a waiting market which absorbed them with comparatively little effort on the part of the producer. Facts are waging a two-fisted battle on guesses, hunches and tips, and facts will win because they are on the side of dividends.

3. I have gained two impressions since I arrived here yesterday. First, from the exhibits I was impressed by the aids to production that had been developed in materials and mechanization that led me to believe that the industry had progressed a long way toward better production. Second, when I scanned the program and saw such an array of highly technical production papers, I shuddered at the thought that I alone must bear the standard of marketing.

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4. Then it occurred to me that several had told me that the industry was production-minded and talked in terms of tonnage. Now in my mind, production is the servant of marketing and tonnage is its result—tonnage at a profit.

5. Nothing is made today except to sell; no wheel turns and no sand is slung except toward an ultimate sale. But the poor lowly casting, the product of this powerful industry, goes out into the world knowing that no industry can well do without it somewhere, somehow, yet feeling that no one is sponsoring it through to its ultimate user because it has no identity—it's "just another casting" of a long line of "just anothers."

6. And so, in this ever-changing day and age, the casting belongs to those things we've always had; and because no one is telling us that we will always have to have them, we wonder if we shouldn't make a change.

7. The competition of industry and industry is almost too well known today to bring up, but it is worth while as an indicator of this spirit of change. Steel and lumber, concrete, both rayon and silk, copper and wrought iron, and so on—these few examples are sufficient.

8. However, the economic law will prevail. The barbers are feeling it even now, when the girls are letting their hair grow long. And if the foundry industry is being warred against, it must develop its logical economic place in the industrial field and not be dislodged from its rightful position by lack of intelligent proclamation to this changing world of its claim for recognition.

9. This, gentlemen, is not a talk on market research and sales analysis. It is, and it is going to be, on merchandising, because I sense the need for the industry to make production the servant of marketing, and not vice versa.

10. To do this, I believe that we should consider reversing the usual procedure of making products from the customers' blueprints and patterns, and we should capitalize the foundryman's knowledge of how to make his product for a definite, known purpose.

11. I was impressed by a folder which came to my desk a few days ago, giving the following series of incidents regarding a certain sale:

"Inquiry received from prominent railroad for cast gear blanks. It was their intention to cut the teeth as per the blueprint. Inquiry was turned over to the engineering department.

All inquiries receive their attention, no matter how simple the job may appear, because our engineers think in terms of parts rather than of tonnage.

"They looked beyond the gear blanks as such and studied the gears and the use to which they were to be put. After careful consideration of all factors involved, they recommended that the teeth be cored instead of cut. A sample set proved very satisfactory. The railroad was so pleased with the initial run that orders for additional castings were placed. The result—a better set of gears for less money."

12. You will note that there was a community of minds, that our engineers think in terms of parts and not tonnage. Now these people are trying to lift themselves out of the ordinary contractor's position into that of producers of castings with a definite use and purpose in mind.

13. I believe that when the foundry industry realizes that it probably knows more about its product than do its customers, and can add an engineering service to its quality and delivery elements, it will be able to look the purchasing agent square in the face and say that six cents or sixty cents is the price, and the production manager upstairs will O. K. the order.

14. A prominent authority told the textile industry recently, "It is a mistaken idea that the buyer is primarily interested in buying goods at the lowest possible price. The fact is, an intelligent buyer does not care particularly what he pays for goods, within reasonable limits. He is interested only in assuring himself to the utmost possible degree that he is getting his goods on as low a basis as they can be bought by anybody else."

15. We should also consider what there is about our product that can be merchandised. Every business has some reason for its existence. If yours is a local business—and I suspect that most foundries are until they have something to merchandise that will overcome the barriers of freight rates, etc. —probably your main reason for existence is the fact that you are located nearby a certain group of casting using industries.

16. What has lifted certain foundries out of the local sphere of operation has been a merchandising sense. You may demur at this and say that it was an alloy or a special facility of some sort, but what created that alloy or special facility? It was the merchandising sense that saw the corrosion problem or the machining problem or the strength problem and built its product to meet a well defined need.

17. Are we building castings today with all the knowledge of the need that is requisite to holding their place against competition from without? How fortunate this industry is that it meets its buyers more nearly face to face than many other industries that have to pass on their enthusiasm for their products through jobbers or wholesalers.

18. Analyze your past sales not alone to see who has bought it and why, but whether the sale has been a profitable one. Then study the extent of the market, the buying elements in it, how best to reach them with your story, how (if at all possible) you can retain the identity of the product through to its ultimate user, and then what can be expected of competition and how to cope with it through the specialized service that you are equipped to give to the exclusion of competition.

19. All of this requires some imagination to develop, although none of it is imaginary. It involves only the merchandising instinct, which, if you get right down to fundamentals, we all have.

20. Castings need not be just castings simply because they have always been just castings. Copper has been just copper up until a few years ago; today, it is a metal that enters into our house building and housekeeping in a hundred different ways. Wire is just wire until some thoughtful merchandising-minded man welds it into squares, backs it with a waterproof paper and sells it by the square yard to replace lath in house building.

21. What an opportunity to step out of the defensive contractor position into that of a cooperative helpful supplier of an essential element.

22. These are days of sales analysis and market research. The battle against production costs, while not won, is well along, and all business is now soberly thinking and planning the battle on the cost of getting the name on the dotted line.

23. It seems to me, however, that the foundry industry has a more elementary job to do. It is not possible that the industry should ponder over the subject of getting bigger and better names on the dotted lines and spending some money to get them. Let us look at what we have to sell, make sure of its soundness, of its many uses, and then start our merchandising thinking.

24. Timken bearings were for automobiles alone until half a dozen years ago, when Timken and several other industries jointly and cooperatively decided that they should be used else-

where. I say jointly and cooperatively because, when the mine-car field was approached, it was with a type of bearing that had been developed by study of mine-car operation, and so on through product after product. A dog sleeps at my young son's door every night. He's a fox terrier until you lift him—then he's just a casting.

25. Now in conclusion I should like to leave with you four principles of selling to industry which apply whether you are a local operator or a nation-wide supplier:

(1) Market determination.
(2) Buying habits.
(3) Channels of approach.
(4) Sales appeals.

26. These can be sub-divided into ten separate steps, as follows:

(1) Markets.
(2) Type of buyers.
(3) Prospect list.
(4) Nature of sales organization.
(5) Territorial plan.
(6) Personnel.
(7) Advertising.
(8) Catalogs and folders.
(9) Conventions, exhibits, etc.
(10) And by far for this industry, the most important buyer-interest keynote, "What should the buyer know about your product? What have you developed to intrigue his interest?"

Value of Analysis and Specification for Core Oils

By J. A. Gitzen,* Milwaukee

Abstract

While the published opinion concerning the value of analysis for making specifications for purchasing core oils is divided, the author believes it is not only possible to purchase core oils by specification but that it is the only proper procedure to follow. As a rule, core oil is the unknown factor in many foundries, and defective castings often are attributed to core oil troubles because of this fact. Specifications may depend on the individual foundry practice, but factors for general specification are given. It is considered possible that any drying or semi-drying oil, with the exception of fish oil, may be used to replace linseed oil, providing its iodine number is 180 or over. The author shows how, when specifications are followed, uniform strength may be obtained in the cores.

1. During the past four years several technical papers have been presented at technical sessions of the American Foundrymen's Association, dealing with the subject of core oil analysis. Unfortunately, opinions are divided on this subject.

2. H. L. Campbell, who has made quite a study of the chemical analysis of commercial core oils along with linseed oil, in one of his papers[1] draws the conclusion that purchasing core oils on chemical analysis is not as safe a procedure to follow as the old method, namely, purchasing them on a strength basis, such as produced in the core when baked. On the other hand, V. A. Crosby[2] and R. D. Wysong[3] in several papers show that,

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[1]*The Qualities of Commercial Core Oils.* Trans. Amer. Foundrymen's Assn., vol. 33, p. 73.

[2]*Core Oil Specifications.* Trans. Amer. Foundrymen's Assn., vol. 35, p. 148.

[3]*Uniformity of Core Oil.* Trans. Amer. Foundrymen's Assn., vol. 37, p. 526.

Table 1

CHEMICAL SPECIFICATION FOR CORE OIL

Specific gravity at 60 degs. Fahr	.9368 Max.
Flash point (Cleveland open), degs. Fahr	165 to 200
Fire point (Cleveland open), degs. Fahr	190 to 225
Viscosity at 100 degs. Fahr. (Saybolt)	155 Max.
Iodine number (Wijs—1 hr. absorption)	154 Min.
Saponification number	136 Min.
Acid number	38-44
Ash	.10 Max.
Color	Light clear amber through ½ in. section
Fish oil	Negative (Griffin test)
Gallonage	U. S. Liquid gallon at 60 degs. Fahr.

with the proper laboratory control, core oils can be purchased successfully and controlled absolutely by buying on chemical specifications.

3. The author will attempt to prove further that it is not only possible to purchase core oils on this basis, but that it is the only procedure to follow by the foundries.

Specify as with Other Foundry Materials

4. There are few foundries that do not buy their pig iron, sands, coke, etc., on chemical analysis. These same foundries, however, not so many years ago purchased their raw materials much on the same basis as they are purchasing core oil today.

5. Has not chemical analysis on the above-mentioned raw materials improved foundry practice tremendously? This, being quite generally conceded, should prove that chemical analysis

Table 2

CORE OIL FORMULA FOR CHEMICAL SPECIFICATION OF TABLE 1

Linseed oil (raw), per cent	50
Rosin (H grade or better), per cent	25
Kerosene (water white), per cent	25

Table 3

MINIMUM LINSEED OIL ALLOWANCE FOR CORE OIL (CHEMICAL SPECIFICATION OF TABLE 1)

Linseed oil (raw), per cent	49
Rosin (H grade or better), per cent	27
Kerosene (water white), per cent	24

covering all raw materials used in the foundry is certainly a step in the right direction. Core oil being one of the important raw materials that enters into the making of good castings, upon its uniformity and quality depend more or less the percentage of scrap and general casting results obtained.

6. The author has had the opportunity during the past five years to observe the practice of a great many foundries, and it is quite generally admitted among many foundrymen that any trouble that develops in the core room usually reverts to the core oil used, whether the latter is at fault or not. Core oil is the unknown in their core practice, and it is only natural that it should be blamed for all troubles.

7. In the majority of foundries when core troubles arise, the core oil that is being used at the time is unjustly thrown out and a new core oil purchased; in a great many cases two or three different oils are tried and still the trouble continues. Finally, however, the trouble is discovered, either in the sand, ovens or somewhere else, but not in the oil.

8. Had the core oil been purchased on specification all of this trouble, loss of time, and poor castings would have been eliminated, because checking the core oil by chemical analysis would have informed the core room immediately that the trouble was from some other source.

What Proper Specifications Should Be

9. The question naturally arises, what would be the proper specification on core oil that should be used in our practice? This depends more or less upon the individual foundry. But, whatever the specification that the foundry adopts, it should be strictly adhered to until such a time as the foundry has found a specification better suited for its work.

10. In this connection, it might be well to consider what is meant by specification or chemical analysis. Let us take, for example, the chemical specification in Table 1.

11. Table 2 gives the formula that is covered by the chemical specification in Table 1.

12. Like any specification, there is a slight flexibility, and the minimum amount of linseed oil that the specification will allow is shown in Table 3. This is true only in case the linseed oil used has an iodine number considerably over 182.

13. All raw linseed oil today is sold by the crushers on

A.S.T.M. specifications, which require a minimum iodine number of 178, but usually commercial raw linseed oil has an iodine number of 180 or over.

Linseed Oil May Be Replaced

14. It is possible that any drying or semi-drying oil, with the exception of fish oil (fish oil is eliminated in the specification by the Griffin test), can be used to replace linseed oil, providing the iodine number is 180 or over. The only one of the commonly known drying oils with a higher iodine number than linseed oil is perilla oil, which ordinarily has an iodine number of 200 to 204.

15. Perilla oil, as a general rule, sells at considerably over the market price of linseed oil. Also, even though mixed with cheaper oils—such as soya bean, corn, etc.—this will not produce

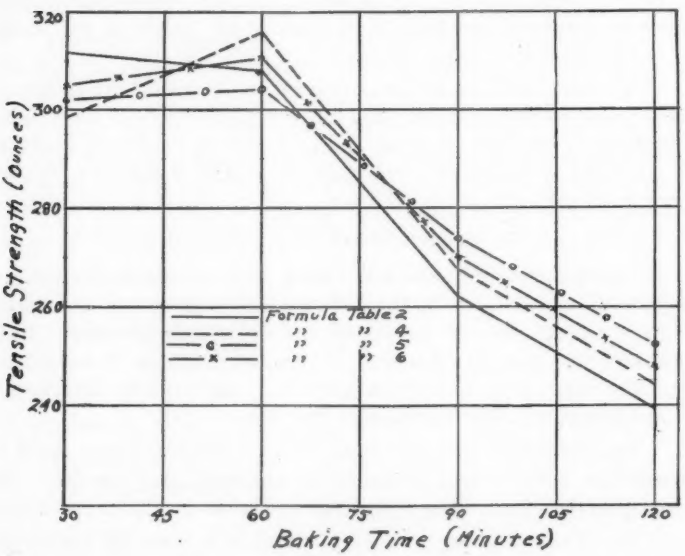

FIG. 1—COMPARATIVE STRENGTHS OF BAKED CORES FROM VARIOUS MIXTURES WHICH MEET SPECIFICATIONS OF TABLE 2. CURVES PLOTTED FROM AVERAGE OF 96 BREAKS ON CORES FOR EACH BAKING PERIOD. BREAK TESTS MADE ON AUTOMATIC TESTING MACHINE USING BAR CORE 8 IN. LONG BY 1 IN. SQUARE, RAMMED ON UNIVERSITY OF MICHIGAN CORE RAMMER. CORES WERE BAKED AT 375 DEGS. FAHR., TEMPERATURE VARYING NOT OVER 5 DEGS. PLUS OR MINUS. SAND RATIO 1000 GRAMS MUSKEGON LAKE SAND RETAINED ON 60 AND 70 MESH; 70 GRAMS WATER; 6½ GRAMS OIL.

such a reduction in cost as would warrant its being substituted in place of raw linseed. However, should it be substituted, no harm would be created so long as the combination of drying oils would retain an iodine number over 180.

16. Fig. 1 shows the comparative tensile strength curves of the different core oil mixes shown in Tables 2, 4, 5, and 6, all meeting the chemical specifications in Table 1.

17. It is quite evident from the curves in Fig. 1 that, if the specification is kept constant, not only the tensile strength

Table 4

CORE OIL MIX—PERILLA AND CORN OILS

Perilla oil, per cent	35
Corn oil, per cent	15
Rosin (H grade or better), per cent	25
Kerosene (water white), per cent	25

Table 5

CORE OIL MIX—PERILLA AND SOYA BEAN OILS

Perilla oil, per cent	35
Soya bean oil, per cent	15
Rosin (H grade or better), per cent	25
Kerosene (water white), per cent	25

Table 6

CORE OIL MIX—PERILLA, SOYA BEAN AND CORN OILS

Perilla oil, per cent	35
Soya bean oil, per cent	7½
Corn oil, per cent	7½
Rosin (H grade or better), per cent	25
Kerosene (water white), per cent	25

but the drying time remains the same. Certainly any one of these oils could be used interchangeably without trouble in the core room.

Iodine Number as Measure of Oxidation

18. The iodine number of drying or semi-drying oils is considered a measure of oxidation, and Fig. 1 proves that this holds true in core oil.

19. Table 7 shows the iodine and saponification numbers of the drying and semi-drying oils used. As stated previously, the iodine number varies considerably with the different oils, but

the saponification number is practically the same. Therefore, it is much more important to specify iodine than saponification, but both, of course, are required to make a solid specification.

Rosin

20. So far, only the drying oils have been considered. Now let us study the second important ingredient, namely, rosin. Table 7 shows the iodine and acid numbers, which are two very important factors. However, there is also a third factor to be considered—color.

21. Under the specification in Table 1, color is designated as light, clear amber through a half-inch section. In order to obtain this color it is necessary to use H grade or better. If

Table 7

IODINE AND SAPONIFICATION NUMBERS OF DIFFERENT CORE OILS

	Iodine No.		Saponification No.
Perilla oil	200.82		191.2
Linseed oil (raw)	182.56		188.94
Soya bean oil	131.4		191.18
Corn oil	130.7		189.86
Rosin	187.65	Acid No.	160.34

light color rosin is used, the iodine and acid numbers will meet the requirements of the specification in that all rosin having a color of H or better will have about the same chemical analysis.

Kerosene

22. The third ingredient used in Table 2 is designated as water white kerosene, which is clear and white in color and free from offensive odor. It is controlled in the specification by the flash, fire and gravity, all of which are interlocking; and unless a good grade of material is used, it is impossible to meet all of the above factors. Water-white kerosene will steam distill out of the green sand core with the water during the baking without producing offensive gases in the core room and leaving no heavy mineral-oil ends behind to interfere with the binding film produced by the drying oil and rosin.

Conclusions

23. Although the iodine number has been stressed more than any of the other factors given in the specification, they all, however, are interlocking and individually carry the same impor-

tance. Each item must be adhered to strictly or the value of the specification as a whole will be destroyed.

24. In all of the author's years of chemical experience in organic analysis and compounds, he has always found that when the chemical analysis was identical, the physical properties produced also were identical. The author is positive that if this is not true, there is a variable factor not controlled by the specification, and the specification should be changed so as to control this factor positively.

DISCUSSION

WRITTEN DISCUSSION

H. L. CAMPBELL:* Every foundry laboratory which has had the responsibility of selecting and inspecting core oils has been interested in the possibility of a chemical test which would indicate the exact quality of any core oil. The test for iodine number has apparently come nearest to a means for establishing the quality of composite core oils. Even this test does not fix the sand-bonding value of oils prepared from a variety of components.

It does not follow, because some foundry materials are purchased on the basis of chemical analysis, that all materials should be specified in this way. Pig iron is of value only because of the chemical composition of the material, while molding sands are specified on the basis of their physical characteristics.

In Fig. 1 of Mr. Gitzen's paper, the physical properties of cores made with certain combinations of oils and other materials are indicated. In order to be of practical value, the results of chemical investigations must be interpreted in strength units. Naturally, the question arises—"Why all the expense of chemical analysis when physical tests of the oil-sand mixtures indicate directly and definitely the real qualities for which the oil is purchased?"

Quoting from a paper by W. R. Pate in Vol 26, *Proceedings* of the American Society for Testing Materials:

"There has been a great deal of investigation by the large consumers of core oil, and a few of these have drawn up their own specifications. They invariably insist upon very high acidity, saponification and iodine values. The manufacturer that can make an oil having these values at the cheapest price secures the business, and as rosin, in normal times, is much cheaper than drying oils, the rosin with the highest acidity, saponification and iodine values is the most economical to use."

It is apparent that it is possible to meet chemical specifications for core oils by means of the use of ingredients other than high-grade drying oils. Therefore, any foundry which insists on chemical requirements must be satisfied with results irrespective of the sand-bonding property or the other essential physical characteristics of good core oils.

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The difficulties in making determinations of iodine numbers of composite core oils have been pointed out by Crosby and Wysong in their paper before the previous A. F. A. convention. Very few foundries are prepared to do this type of analytical work. On the other hand, it is possible for any foundry to prepare standard test cores with an unknown oil, to bake these cores under established conditions and to measure the properties of these cores. In this way the practical value of any core oil may be definitely ascertained.

ORAL DISCUSSION

CHAIRMAN CONE: Perhaps Mr. Gitzen would like to reply to that, so I will give him an opportunity.

J. A. GITZEN: In answer to Prof. Campbell's written discussion, in the first part he says, "It does not follow, because some foundry materials are purchased on the basis of chemical analysis, that all materials should be specified in this way. Pig iron is of value only because of the chemical composition of the material, while molding sands are specified on the basis of their physical characteristics."

I know of quite a number of steel foundries that do make a silicon determination chemically on molding sand; also, some of the gray iron foundries are doing some chemical analysis work on their sands.

It is possible that chemical analysis on sands is not, as yet, the proper procedure to follow. These tests are not as common and not near as much work has been done on them as from a physical standpoint. However, the fact still remains that physical and chemical analyses usually go hand in hand, and the general trend in the industry today is to standardize from a chemical angle and then, if the physical method of determination is easier, to adopt that procedure.

The part that Prof. Campbell quotes given by W. R. Pate at the A. S. T. M. meeting several years ago was from a discussion of rosin. The purpose of that meeting was to find out where it was possible to apply more rosin—to find industries or places in industry by doing things with rosin, to improve its quality or characteristics so that more of it could be used. What Mr. Pate tries to bring out in this statement is that, if the rosin producers can produce rosin with a higher saponification value with a higher iodine value, it would be possible to use more in the replacement of drying oils in core oils. That, of course, would be quite a problem, it would need a lot of chemical investigation and it is possible that it could never be done.

However, that was a suggestion as to a possible increased outlet for rosin in the core-oil industry, which is a large consumer of rosin.

Prof. Campbell again states that it would be possible to meet chemical specifications in this case with rosin by using more of it to replace drying oils—which naturally are the basic binders—and he states: "Therefore, any foundry which insists on chemical requirements must be satisfied with results irrespective of the sand-bonding property or the other essential physical characteristics of good core oils."

In my paper I tried to bring out that whatever chemical factors of

a specification hold true and are right, and if the specification is sound, the physical characteristics must follow. That is why I showed the chart of Fig. 1, showing the tensile strength of the cores made with different formulas, all meeting the specification, so as to prove to foundrymen who would be skeptical if I merely stated that these formulas will all produce the same tensile strength cores.

Try these out with your own sands. Replace No. 2 formula with formula No. 4 and you will get the same results. Try it and prove to yourself by checking with a physical test bar so that there will be no doubt as to my statement.

Prof. Campbell brings out that the iodine numbers are hard to determine and that the expense connected with making chemical determinations was not necessary. All that is needed to check these specifications from a chemical standpoint are a few burettes, some standard half-normal sulphuric acid solution which can be made up in the laboratory, a hydrometer, and a flash and fire apparatus, if you feel it is necessary. If flash and fire are set into the specification, of course you should have the apparatus, but I do not believe the total investment in the equipment necessary to make the chemical analysis would cost over $25 or $30.

Once a method has been adopted which is standard for the analysis, I believe anybody in the laboratory can run a complete analysis covering all points of this specification in a period of two hours and probably have time to do other things in between. For instance, making an iodine number determination would take one hour. It takes only a short while to lay it out and get started and then the worker would have to wait an hour before titrating it.

WALTER F. GRAHAM: In the first place, I wish to compliment the author for his attack on a very intangible matter, namely, the application of specifications to a liquid organic mixture, and to attempt from certain chemical values to determine the value of that mixture in service.

I think the matter of specifications—not necessarily as a checking of the producer from the standpoint of failure to supply proper material, but to arrive at a common understanding of the value of his product—is very necessary. My remarks, therefore, are not as criticism of the subject matter of the paper, but a query as to how the subject matter may be put into practical use by the user of core oil.

The difficulties that trouble us are right along this line. We are users of linseed oil for the reasons that I wish to discuss, with the exception of the first reason, in which we question the actual value of core oils as compared with linseed oils in many cases.

The second reason is that we have no definite knowledge of the composition of the core oils from our contact with the producers.

The third reason is that we have no definite way of putting into practice the values, that we might determine in the laboratory, of the unknown composition.

Having been approached over a period of fifteen years by core-oil salesmen, I cannot remember one single instance in which the core-oil salesman gave any indication that he was willing to impart knowledge regarding the actual composition of his oil.

Working from the analysis to the composition has been a matter that has troubled, I believe, anybody knowing the analysis but having no idea whatsoever of the composition. I brought our chemist here, Miss White, and specifically asked her if she—from an analysis along lines which are standard—could accurately deduce an absolutely unknown composition, and she says, "Not necessarily"—which, of course, is a rather indefinite proposition.

Furthermore, it would seem that, while the author very clearly shows some correlation between the analysis and properties, he was aware of the primary composition of the core oil before drawing his conclusions. I wonder what would have happened if an unknown sample had been submitted to him to make the same deductions.

MR. GITZEN: This is just one phase of chemical analysis. There is another method that you can follow such as we use in our laboratory on an unknown sample. First of all, during the analysis, you determine the iodine, saponification and acid values, but you do not stop there. When you take your acid number, you take your solution and separate it, decompose it and throw out all of your material that is acid.

By the color of the separated rosin, you can determine practically the color used originally. By the melting point you can determine whether any fatty acids have come from your drying oil, as the fatty acid from the drying oil will have a much lower melting point than rosin.

In the saponification reaction we make a separation and we get all of the drying oil in the form of a fatty acid. If it is linseed oil, you have just the linseed fatty acid. If you have corn oil or chinawood oil in combination with linseed, you get a combination of fatty acid.

By taking an index of refraction of these fatty acids you can calculate within two or three per cent of the mixtures you have. In other words, if you have 25 per cent linseed with 25 per cent chinawood oil, by saponifying and separating into fatty acids and taking an index of refraction you could get within two or three per cent of the quantity of chinawood oil with which the linseed oil has been adulterated. You could do the same thing with corn oil.

Then what you have left after your separation would be your solvent. That solvent could be determined on the original core oil with steam distillation, which takes out all the volatile. By heating the flash up to 250 degs. Fahr. and running in steam, you get off all of the kerosene or volatile solvent. Then take a sample of the material left in the flask, add caustic and separate out all of your rosin and your linseed. Take the top layer, which is petroleum ether, separate that off, and you have whatever mineral oil is present.

If gas oil is used as a solvent, you will get a certain percentage of mineral oil left behind in the petroleum ether. If mineral oil is added to linseed oil, that also will stay behind.

In other words, you can separate the three constituents and have them individually. Put them back together and you have your original product.

Methods for Determining the Volume Changes Undergone by Metals and Alloys During Casting*

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Abstract

A study of the influence of the shrinkage undergone by metals during casting upon the production of sound castings of predetermined size was divided into two major phases: (1) A study of the volume changes undergone by metals cooling from the liquid state to room temperature, such changes being considered as definite physical properties of the metal quite apart from variables in foundry practice; (2) A study of the relation of variables in foundry practice to the amount and distribution of the shrinkage cavities or other evidences of volume changes which remain in a finished casting. The present paper reviews methods which have been proposed and used for determining the various types of shrinkage undergone by a cooling metal; defines (as the three types of shrinkage to be considered) "liquid shrinkage," "solidification shrinkage" and "solid shrinkage"; considers in detail the sand-cast-cone method for determining shrinkage during casting and the more fundamental procedure of constructing a specific volume-temperature curve for each metal or alloy from room temperature to some temperature well above the melting point or melting range. The specific-volume temperature curve in the range of liquid metal—the liquid contraction curve—is constructed from data secured by application of the crucible immersion method, i. e., by filling a crucible of known volume with the liquid metal at known temperature. The mass of the liquid metal at the temperature of filling the crucible is the same as the mass of the solidified contents of the crucible at room temperature. Hence, the liquid specific volume is readily calcu-

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lated. The curve in the range of solid metal—the solid contraction curve—is constructed from data given by direct observations of the change in length with change in temperature of a sand-cast bar of metal. The difference between the specific volume of the solid metal and of the liquid metal at the melting point is the "solidification shrinkage." Or, in the case of an alloy, the solidification shrinkage is the difference in specific volume at the beginning and at the end of the freezing range.

INTRODUCTION

1. In 1928 the American Foundrymen's Association, through its Committee on Gray Iron Castings, discussed with the Bureau of Standards the desirability of an investigation on the "liquid shrinkage" of metals. Following preliminary considerations and a general survey of the problem, a research associate was appointed to work on the investigation.

2. It soon appeared, however, that the information desired by the practical foundryman involved much more than could properly be included under the term "liquid shrinkage." The foundryman, in producing a satisfactory casting, has a three-fold interest in the shrinkage problem:

3. First, he must make the dimensions of his pattern greater than the desired dimensions of the final casting, allowing for pattern maker's shrinkage.

4. Second, he must employ all means possible and within his knowledge to attain the maximum density in the casting and to produce a metal free from porosity, pipe and gas holes.

5. Third, he must consider the design of his casting in its relation to the liability of the casting to crack in the mold due to stresses set up by differential shrinkage at sharp angles or abrupt changes in cross-section or to shrinkage of metal about cores.

Three Types of Contraction Defined

6. When a metal or alloy is cooled from any temperature in the liquid state to ordinary temperature, a change of volume takes place. This change is the algebraic sum of three consecutive volume changes which may, for the purposes of the present paper, be designated and defined in the following terms:

(1) Liquid shrinkage or contraction is the change in vol

ume on cooling from any temperature in the liquid state to some lower temperature in the liquid state.

(2) Solidification shrinkage or contraction is the volume change of a pure metal in passing from the liquid state to the solid state at the freezing point, or the change in volume of an alloy in passing from the liquid state at the beginning of the freezing range to the solid state at the end of the freezing range. The solidification shrinkage of a eutectic or an intermetallic compound, freezing at a constant temperature, may be defined in the same manner as that of a pure metal.

(3) Solid shrinkage or contraction is the change in volume on cooling from some temperature in the solid state to a lower temperature in the solid state.

Discussion of Types of Contraction

7. As defined above, the solidification shrinkage of an alloy with a freezing range will include, therefore, all three types of shrinkage named, i. e., liquid, solidification and solid.

8. Liquid shrinkage or contraction is a definite physical property of a metal or alloy. This value, therefore, is fixed and constant for each metal or alloy in any type of casting and in any foundry.

9. The solidification shrinkage or contraction is likewise a constant for a pure metal, eutectic or intermetallic compound. However, in alloys exhibiting solid-solution phenomena, the solid metal separating from the melt is continually changing in composition.

10. During this selective crystallization stresses may be created in the solid metal, due to the difference in the coefficient of expansion of metal of different composition. These stresses tend to change the solidification shrinkage as defined above, the difference between the true and apparent solidification shrinkage being smaller the nearer the solid metal in the solidification range approaches uniformity of temperature and composition.

11. The solid shrinkage or contraction of a metal or alloy is variable. It is to be expected that stresses will be set up in a cast alloy exhibiting solid-solution phenomena, not only during the solidification range but also below this range. These stresses are due partly to the temperature gradients set up during cooling and partly to different coefficients of contraction of metal of different composition.

12. As a result of these stresses set up in a cast alloy, the observed contraction of a bar designated as pattern maker's

shrinkage differs from the true thermal expansion of the alloy. In determining the thermal expansion of an alloy, the specimen is heated or cooled nearly uniformly. The alloy attains temperature equilibrium and tends to approach composition equilibrium. This situation makes it impossible to determine the shrinkage or contraction of a solid alloy casting by using thermal expansion measurements.

13. In pure metals, eutectics and intermetallic compounds, which freeze at constant temperature, the stresses resulting from cooling usually are small. Hence, the solid shrinkage or contraction of these metals and the thermal expansion data can be expected to coincide and often do.

14. Another factor which influences the difference between the true thermal expansion of a metal or alloy and the pattern maker's shrinkage is the apparent failure of a casting to register the true shrinkage taking place at and somewhat below the freezing point or range.

15. The cause of this failure of a casting to register the true shrinkage is possibly due to the material at the grain boundaries not possessing sufficient rigidity to register the actual contraction of the grains or crystallites. It also is to be expected that the cast density of a metal as commonly made in the foundry is always less than the true density of that metal or alloy.

16. Furthermore, thermal expansion in the literature are not applicable to gray-iron castings because of the allotropic transformations or changes in structure undergone during cooling from the melt. The compressibility of a metal is so slight that pressure is disregarded in these considerations.

17. It would be of interest to know the relative tendencies of metals and alloys to distribute their shrinkage between an external pipe and internal voids. Except where conditions are such as to form a complete rigid shell about a cooling mass of molten metal before all have reached the freezing temperature, the shrinkage due to liquid contraction will form a depression on the upper surface (external pipe).

18. It is believed that under normal conditions, the shrinkage that takes place during the change of state contributes largely to the production of internal voids when such tendency is exhibited by the metal or alloy. This characteristic to form internal voids is not so pronounced in pure metals as it is in some alloys, which, by nature of the mechanism of solidification,

tend to distribute the solidification shrinkage volume throughout the entire casting.

Distribution of Solidification Shrinkage

19. The distribution of the solidification shrinkage or contraction—whether in the form of an external pipe, internal pipe or small cavities (porosity) throughout the casting—will depend largely on the following factors:

(1) The amount of solidification shrinkage,

(2) The freezing temperature of the metal.

(3) Type of metal, whether it is (a) pure, (b) eutectic, (c) intermetallic compound, (d) solid solution, (e) any combination of (b), (c) and (d).

(4) Fluidity of the metal.

(5) Heat conductivity, heat capacity and pouring temperature of the metal.

(6) Location and design of gates and risers.

(7) Ratio of surface area to volume.

(8) Heat capacity, heat conductivity and initial temperature of the mold material.

20. Factors (1), (2), (3), (4) and (5) may be grouped as properties of the metal, while the remaining factors may be classed as foundry or casting practice or technique.

21. It is obvious, from the number and complexities of the factors influencing the amount and distribution of the shrinkage in the casting of any particular metal or alloy that it is very difficult—if, indeed, possible—to determine the influence of all these various factors by means of any single experimental procedure.

Two Major Phases in Study of Shrinkage Properties

22. A consideration of the influence of the shrinkage properties of the metals might well precede the study of foundry practice. Therefore, the problem has been divided into the following two major phases:

Development of methods for studying the shrinkage properties of the metals.

A study of the relation of these shrinkage properties of cast metals to foundry practice.

23. The present report is concerned only with the first of these two phases.

REVIEW OF PREVIOUS METHODS

24. Methods that have been previously employed for measuring the volume changes undergone by a metal in cooling from the liquid state to room temperature may be reviewed under four classes:

(1) Dilatometric.
(2) Buoyancy.
(3) Pyknometer.
(4) Sand-cast sphere, cone and cylinder.

DILATOMETRIC

25. Dilatometric methods consist in observing the change in length or volume of a given material with change in temperature. In the solid state the specimen is usually in the form of a bar and the change in length is measured directly. For observing the change in volume with change in temperature in the liquid state, the molten metal is heated or cooled in a container of known volume calibrated to read the corresponding volume change directly.

Dilatometric Methods to Determine Specific Volume

26. Dilatometric methods have been employed by a number of workers[1, 2, 3, 4, 5] for determining the specific volume of metals in the liquid state.

27. A differential dilatometer was used by Goodrich[6] for determining the specific volume of a number of low-melting metals and alloys in the liquid and solid states and through the solidification range. In this method, the metal sample is placed in one of two similar bulbs and the difference in pressures in the bulbs with change in temperature is observed.

28. These methods are limited to low-melting-point metals and alloys for want of suitable refractories. Also, to measure the actual change in volume the metal undergoes during solidifi-

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[1] E. Wiedmann. *The Volume Changes of Metals and Alloys During Melting.* Annalen der Physik, vol. 20 (1883), p. 228.

[2] Vincentini and Omodei. Atti R. Accad. Scienza, Torino, vol. 23 (1887), p. 8.

[3] C. Ludeking, *The Density of Molten Bismuth.* Annalen der Physik, vol. 34 (1888), p. 21.

[4] M. Toepler, *The Examination of the Volume Changes During Melting for a Number of Elements.* Annalen der Physik, vol. 53 (1894), p. 343.

[5] Y. Matuyama, *On the Density of Molten Metals and Alloys.* Science Reports, Tohoku Imperial University, vol. 18 (1929), p. 19.

[6] W. E. Goodrich, *Volume Changes During the Solidification of Metals and Alloys of Low Melting Point.* Transactions, Faraday Society, vol. 25 (1929), p. 531.

cation requires extreme precaution in guarding against the formation of internal cavities, which appreciably influence the validity of the results.

29. Benedicks, Berlin and Phragmen[7] determined the density of molten tin, lead and finally low-carbon iron by making a double manometer and comparing the height of a column of the liquid metal with that of a column of mercury supporting the same gaseous pressure. Great ingenuity was shown in the construction of U-tubes of refractory material capable of retaining the metal and, at the same time, supporting the requisite pressure of nitrogen or other inert gas.

30. Recently, Benedicks, Ericsson and Ericson[8] with an apparatus similar to the one mentioned in the preceding paragraph, determined the specific volume—that is, the volume in cm.^{3} of one gram of material—of iron, nickel and iron alloys in the molten state.

Determination of Solid Contraction

31. An approximate determination of the solid contraction of a cast metal may be made by a method originally developed by Keep.[9] The method consisted in measuring the change in length of a cast bar as it cools from the freezing temperature to room temperature. This method was later used by Turner and his students[10, 11, 12, 13, 14, 15] and also by Wüst.[16]

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[7] C. Benedicks, D. W. Berlin and G. Phragmen, *A Method for the Determination of the Specific Gravity of Liquid Iron and Other Metals of High Melting Point.* Iron and Steel Inst., Carnegie Scholarship Memoirs, vol. 13 (1924), p. 129.

[8] C. Benedicks, N. Ericsson and G. Ericson, *Bestimmung des Spezifischen Volumes von Eisen, Nickel und Eisenlegierungen im Geschmolzenen Zustand,* Archiv für das Eisenhüttenwesen, vol. 3 (1930), p. 473.

[9] W. J. Keep, *Cooling Curves and Tests for Cast Iron.* Journal Iron and Steel Inst., vol. 48 (1895), p. 227.

[10] T. Turner, *Volume and Temperature Changes During the Cooling of Cast Iron.* Jour. Iron and Steel Inst., vol. 69 (1906), p. 48.

[11] T. Turner and M. T. Murray, *The Copper-Zinc Alloys—A Study of Volume Changes.* Jour. Inst. of Metals, vol. 2 (1909), p. 98.

[12] D. Ewen and T. Turner, *Shrinkage of Antimony-Lead Alloys and of Aluminum-Zinc Alloys During and After Solidification.* Jour. Inst. of Metals, vol. 4 (1910), p. 128.

[13] A. Hague and T. Turner, *The Influence of Silicon on Pure Cast Iron.* Jour. of Iron and Steel Inst., vol. 82 (1910), p. 72.

[14] J. L. Houghton and T. Turner, *Volume Changes in Alloys of Copper with Tin.* Jour. Inst. of Metals. vol. 6 (1911), p. 192.

[15] J. H. Chamberlain, *A Study of Volume Changes in Alloys.* Jour. Inst. of Metals, vol. 10 (1913), p. 193.

[16] F. Wüst, *Shrinkage of Metals and Alloys.* Metallurgie, vol. 6 (1909), p. 769.

32. Anderson [17] determined the pattern maker's shrinkage of a number of alloys by casting a bar in a mold of known length. The difference between the length of the resulting bar and the original mold length was the change due to solid contraction of the cast metal.

BUOYANCY

33. Buoyancy methods consist, in principle, in measuring at various temperatures the buoyant effect of an inactive liquid of known density and thermal expansion upon a definite mass of the metal under examination. For lower temperatures an oil is used, while molten sodium chloride or similar salts are used for higher temperatures.

34. This method was used by Bornemann and Sauerwald,[18] Endo,[19,20] Honda and Endo,[21] Russell, Allen and Goodrich[22] Matuyama,[23,24] and Honda, Kase and Matsuyama[25].

35. It has been pointed out by Goodrich[6] that the results from this method are subject to several inaccuracies:

(a) When investigating low-melting-point alloys and metals, the liquid heating bath is usually an oil, the density of which changes not only with temperature but also with time at higher temperature.

(b) Correct temperature of the specimen is not readily obtained at the time of making the determination. Since the volume changes were always determined during changes of temperature, the change in temperature of the metal would always lag behind that indicated by the thermometer. Temperature gradients may exist in the heating or cooling bath itself, since any method of stirring would interfere with the method used to determine the buoyancy.

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[17] R. J. Anderson, *Linear Contraction of a Series of Brasses and Bronzes*, TRANS. Amer. Fdymen's Assn., vol. 31 (1923), p. 371; and *Linear Contraction and Shrinkage of a Series of Light Aluminum Alloys*, TRANS. Amer. Fdymen's Assn., vol. 31 (1923), p. 392.

[18] K. Bornemann and F. Sauerwald, *Density Measurements of Metals and Alloys*. Zeit. f. Metallkunde, vol. 14 (1922), p. 145.

[19] H. Endo, *On the Measurement of Change of Volume During Solidification*. Sci. Repts., Tohoku Imp. Univ., vol. 13 (1924), p. 193.

[20] H. Endo, *On the Volume Change in Alloys During Solidification*. Sci. Repts., Tohoku Imp. Univ., vol. 13 (1924), p. 219.

[21] K. Honda and H. Endo, *On the Volume Change in Cast Iron During Solidification*. Sci. Repts., Tohoku Imp. Univ., vol. 16 (1927), p. 19.

[22] Russell, Allen and Goodrich, British Nonferrous Metals Research Association Report, ser. 85 (1925).

[23] Y. Matuyama, *On the Volume Changes in Certain Type Metals During Solidification*. Sci. Repts., Tohoku Imp. Univ., vol. 17 (1928), p. 1.

[24] Y. Matuyama, *On the Volume Change of Manganese During Solidification*. Sci. Repts., Tohoku Imp. Univ., vol. 18 (1929), p. 733.

[25] K. Honda, T. Kase and Y. Matsuyama, *On the Change of Volume of Cast Iron During Solidification*. Sci. Repts., Tohoku Imp. Univ., vol. 18 (1929), p. 699.

36. In a recent article by Matuyama[24] the following note occurs:

"In his recent report, W. E. Goodrich[6] remarked that the present method (that is, the buoyancy method) is inaccurate for the reason of the temperature lag; but this remark comes from his misunderstanding and, in fact, the method is sufficiently accurate in determining the amount of volume change of a substance during its solidification, provided the substance shows no undercooling, for the necessary quantity required for calculation of the volume change is the abrupt change of the scale deflection, but not the temperature itself, and the deflection-temperature curve may be drawn equally well as the deflection-time curve."

Some Consideration of Density

37. As in the dilatometer method for determining the change in volume during solidification, gas bubbles or shrinkage cavities may be formed inside the specimen, which would seriously affect the results of a determination.

38. Desch and Smith[26] have attempted to determine the density of molten steel by observing the weight of a sinker attached to one arm of a balance in air, mercury and liquid steel. It is difficult to select a suitable sinker that is not attacked by the liquid steel, and the mechanical difficulties during the progress of a determination are great indeed.

Pyknometer

39. Edwards and collaborators[27, 28, 29] have measured the specific volume of molten aluminum and copper-aluminum alloys by means of a form of pyknometer, which the authors called a "densimeter." A crucible of known volume was filled with molten metal at a definite temperature and the metal allowed to freeze. This process was repeated for several other temperatures.

40. The weight of the resulting ingots and the volumes of the crucible at the respective sampling temperatures gave infor-

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[26] C. H. Desch and B. S. Smith, *Interim Report on the Density of Molten Steel.* Jour. Iron and Steel Inst., vol. 119 (1929), p. 538.

[27] J. D. Edwards and F. A. Mooremann, *Density of Aluminum from 20 to 1000 Degs. Cent.* Chem. & Met. Eng., vol. 24 (1921), p. 61.

[28] J. D. Edwards, *Mechanism of Solidification of a Copper-Aluminum Alloy.* Chem. & Met. Eng., vol. 24 (1921), p. 217.

[29] J. D. Edwards and H. T. Gammon, *Causes of Piping in Aluminum Ingots* Chem. & Met. Eng., vol. 24 (1921), p. 338.

mation from which the specific volume-temperature curve in the liquid state was constructed. The method is sufficiently accurate, but like most methods it is applicable only over a limited temperature range.

SAND-CAST SPHERE, CONE AND CYLINDER

41. Several attempts to measure the total shrinkage of cast iron due to liquid and solidification shrinkage have been made by comparing the weight and volume of an unfed cast specimen with the weight and volume of a similarly cast but "sound" specimen. The weight of the sound or "reference" specimen was obtained from a fed casting or from the calculated weight the specimen should have had as determined from the volume and the maximum density of the metal (usually that at the gate). The difference in weight between the unfed casting and the sound or reference specimen represents the combined liquid and solidification shrinkage of the metal.

42. An attempt to determine the total amount of liquid and solidification shrinkage of gray cast iron was made by West,[30] who cast two spheres of the same dimensions, feeding one from a heavy riser and the other without any feeding, and comparing the weights of the two spheres. He repeated his experiments by increasing the size of his spheres. His results were not consistent.

43. Smalley[31] conducted a series of experiments on gray cast iron, casting conically shaped specimens to determine the relation between solidification shrinkage and the tendency to form a pipe.

44. Longden[32] employed cylinders and spheres fed and unfed. Schwartz [33] cast four spheres from the same runner and calculated the shrinkage from the density of the gate and the volume of the resulting spheres.

Methods Appear to be Practical Tests

45. The methods used by these investigators are all the same in principle and all appear to be practical foundry tests.

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[30] Thomas D. West, *Molders' Text Book*. John Wiley & Sons (1909), p. 6.

[31] O. Smalley, *Volume Changes of Cast Iron on Solidification*. Inst. of Brit. Fdymen., vol. 16 (1922-23), p. 405.

[32] J. Longden, *Some Considerations on Liquid Shrinkage in Gray Cast Iron*. Inst. of Brit. Fdymen., vol. 18 (1924-25), p. 573.

[33] H. A. Schwartz, *Shrinkage in White Cast Iron*. TRANS. Amer. Fdymen's Assn., vol. 37 (1929), p. 205.

It is difficult, however, to determine whether the total shrinkage due to liquid and solidification contraction is actually represented by the values obtained or just what is measured.

46. These methods do not differentiate between the shrinkage due to liquid contraction and that due to solidification contraction. However, they may have great value when interpreted in the light of shrinkage values of a metal as it passes through the three stages of contraction. This point will be made clearer when discussing the cone-casting method which follows.

Methods Used in the Present Investigation

47. The methods used in the present investigation for determining the volume changes undergone by a metal when it is cooled from any temperature in the liquid state to ordinary temperature, are described in the following sub-sections:

Sand-Cast Cone

48. A sand-cast-cone method was employed in the beginning

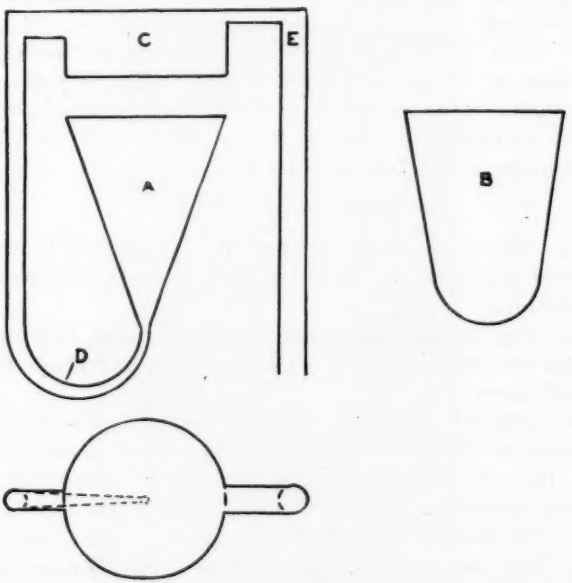

Fig. 1—Sand-Cast Cone Shrinkage Specimens. *A:* Cone Specimen. *B:* Modified Cone. *C:* Pouring Basin. *D:* Horn Gate. *E:* Overflow.

of this investigation in an attempt to determine the combined liquid and solidification shrinkage of metals and alloys. A sand-cast cone, shown in Fig. 1, *A*, was designed to be cast base up with a pouring basin directly over the base of the cone. It was intended that this pouring basin would retard the freezing on top of the inverted cone and thus localize the external pipe in the top portion of the casting.

49. The cone casting was bottom-poured to prevent, or keep at a minimum amount, the solidification of any metal until the mold cavity was completely filled. The junction of the horn gate to the casting was purposely made small so that it froze when pouring ceased. Thus the body of metal in the cone cavity was isolated and no feeding action took place. The pouring basin was provided with an overflow to aid in keeping a constant pressure head during the casting operation.

50. A modified cone of the type shown in Fig. 1, *B*, was used in an effort to study the effect of size and shape of the test specimen upon the tendency to pipe externally or to form internal voids. The modified cone consisted of a truncated cone completed with a hemisphere of 2-in. radius.

51. This latter cone *B* has a volume approximately two times that of cone *A*, and the rate of cooling of any particular section was slower due to the smaller ratio of surface to volume. The second type of casting, *B*, was molded and poured in the same manner as the regular cone *A*.

Molding and Pouring

52. The molds were all oven dried previous to casting. The mold and horn-gate orifice were faced with a special core-sand mixture.

53. Fig. 2 is a photograph of an aluminum cone casting, showing the positions of the pouring basin, overflow, feeding and horn gate.

54. Fig. 3 is a photograph of a cross-section through a type *B* aluminum casting, showing the relative size of the external pipe. The specimen has been deep etched to exhibit the distribution of inter-crystalline shrinkage.

55. In casting a specimen of the above type, metal was poured from the ladle into the pouring basin. As the level of the metal in the pouring basin rose to the gate level, metal flowed down the gate and entered the mold cavity from the

bottom. The flow of metal from the ladle was then adjusted to maintain a stream of metal over the overflow of the basin (Fig. 1, *E*).

56. When the mold cavity was completely filled with liquid metal, it was assumed that the horn gate solidified and isolated the casting. When the cone of liquid metal cooled and started to freeze, a solid and continuous shell formed, fitting the conical surface of the mold.

57. The casting has a tendency to form an external pipe during the period of liquid and solidification contraction in the middle portion of the base. The volume change due to solidification contraction may or may not appear in the form of an external pipe. It may appear as an internal pipe or as voids distributed throughout the casting.

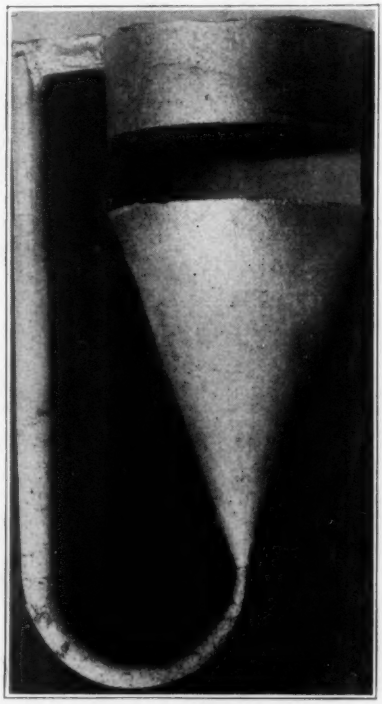

Fig. 2—Aluminum Cone Casting, Gate and Pouring Basin.

Some Factors Encountered

58. The originally formed shell, which ultimately included all the metal of the casting, decreased in volume on cooling to room temperature. The volume of the external pipe or the internal cavities were likewise reduced in the same proportions as was the volume of the entire specimen.

FIG. 3—DEEP-ETCHED SECTION THROUGH MODIFIED CONE CASTING OF ALUMINUM.

59. Consequently, the ratio of the liquid and solidification contraction volumes to the volume of the entire casting at room temperature will be the same as the relation of these same volumes at the freezing point or the end of the freezing range.

60. Hence, by refilling any external pipe in the finished casting and making the filled-out casting conform to the shape of the pattern, the specimen will then represent the volume the casting would have assumed had there been no contraction other than solid. Therefore, the difference between the waxed volume and true volume of the casting represents the combined volumes of the liquid and solidification shrinkage at room temperature.

61. It is necessary to know the density of the metal under examination. The accuracy of the determination made from these measurements depends in part upon the value used for the density.

Measuring Temperature to Evaluate Shrinkage

62. Several attempts were made to measure the temperature of the molten metal in the conical test specimen at the instant the mold was filled. Such temperature measurements are necessary to evaluate the liquid and solidification shrinkage. From the several measurements made, it was observed that the metal cooled to the solidification temperature very rapidly.

63. The calculations are as follows:

Let

W_c = the weight of the specimen as cast.

Let

D = true density of the metal at room temperature;

Then

$\frac{W_c}{D} = V$, the true volume of the metal at room temperature.

Let

V_c = the apparent volume of the specimen as cast and

V_w = "waxed" volume of the specimen;

Then

$$\frac{V_w - V}{V_w} = \frac{X}{100} \text{ or}$$

$$X = \frac{(V_w - V)}{V_w} \times 100 \qquad (1)$$

where X is the percentage volume change due to liquid plus solidification shrinkage.

Similarly,

$$\frac{(V_w - V_c)\ 100}{V_w} = \text{per cent volume change appearing as external pipe} \qquad (2)$$

and

$$\frac{(V_c - V)\ 100}{V_w} = \text{per cent volume change appearing as internal voids.} \qquad (3)$$

64. It is obvious that the sum of expressions (2) and (3) is equal to equation (1).

65. Twenty-four specimens were cast, 19 of type *A* and five of type *B*. Some of these specimens were defective. Table 1 gives the data on 12 castings.

Table 1

DATA ON CONICAL SAND-CAST SPECIMENS

Specimen No.	Type	Metal.	Weight, grams.	Pouring temp., degs. Cent.	Average density, grams per cm.³	Vol. of external pipe, per cent.	Vol. of internal voids, per cent.	Vol. of liquid plus solidificat'n shrinkage, per cent.
3	A	Aluminum	3,168	....	2.68	6.67	0.94	7.62
7	A	Cast iron	8,917	1,450	7.17	1.71	...	...
8	A	Cast iron	9,053	1,250	7.08	0.00	...	...
9	A	Aluminum	3,104	740	2.65	4.76	0.55	5.31
10	A	Aluminum	3,163	755	2.62	3.26	2.83	6.09
11	A	Aluminum	3,118	900	2.60	3.83	3.88	7.71
13	A	Aluminum	3,151	800	2.60	5.55	1.50	7.05
14	B	Aluminum	5,493	800	2.64	6.76	2.11	8.87
15	A	Tin	9,296	340	7.27	3.03	0.05	3.08
16	B	Tin	16,210	340	7.28	3.06	0.00	3.06
17	A	Zinc	8,780	516	7.10	4.37	0.07	4.44
18	B	Zinc	15,268	516	7.09	4.68	0.09	4.77

Comments on Data of Table 1

66. Several comments may be made on the data given in Table 1. If it is assumed that the mold cavity can be filled completely with molten aluminum of uniform temperature just at the melting point, the total shrinkage (other than solid) of the resulting casting would then be the shrinkage due to solidification alone.

67. The total shrinkage values for aluminum specimens Nos. 9 and 10, Table 1, as determined by this method were 5.31 and 6.09 per cent, respectively. It was later found that the

solidification shrinkage for this metal was actually 6.6 per cent, a value in close agreement with values obtained by Edwards and Mooremann,[27] and by Endo[19].

68. Specimens Nos. 13 and 14 were poured at the same ladle temperature. The total shrinkage values differ by 1.82 per cent. Specimen No. 13 represents type *A* casting, and No. 14 represents type *B* casting.

69. Type *A* specimen having a greater ratio of surface to volume, has a greater surface cooling tendency for a given mass of metal than type *B*. There will be, therefore, more metal chilled or solidified *during* the pouring period in type *A* casting, and the diminution in volume due to this chilling or solidification will be replaced by the incoming liquid metal. That is, there will be more feeding of the casting during the pouring period in type *A* casting than in type *B*.

70. Practically the same values for total shrinkage were obtained in casting tin for both type *A* and type *B* specimens. In the case of zinc, there is a difference of 0.33 per cent, the larger value being given by type *B* specimen.

71. Since chilling action is a function of temperature gradient between the liquid metal and the surface of the mold cavity, the discrepancies due to variations in the amount of feeding will increase as the freezing temperature of the metal increases.

True Shrinkage Values Not Obtained by This Method

72. It is obvious that true shrinkage values were not obtained by this method, presumably for the following reasons:

(1) The temperature of the metal at the instant the mold cavity is completely filled cannot be determined because there is no uniformity of temperature throughout the mass of liquid metal. There is an appreciable temperature gradient from the center of the specimen to the surface in this or any other similarly shaped and cast specimen.

(2) A volume change takes place in some of the metal during the pouring period. The molten metal in contact with the sand surface will receive more or less chill and a solid shell of metal will be formed while the specimen still is being poured. The solidification shrinkage due to this freezing metal is replaced by additional molten metal entering the mold cavity, thus diminishing the true shrinkage of the casting.

73. Therefore, no further consideration of this method was given at this stage of the investigation. However, it is realized that a method of this type may be quite useful and satisfactory in further phases of this investigation when attention is turned to the influence of foundry variables upon the distribution of the various types of shrinkage.

DETERMINATION OF THE SPECIFIC VOLUME-TEMPERATURE CURVE

74. It has already been pointed out that when a metal or alloy is cooled from any temperature in the liquid state to the solid state at room temperature, a change in volume takes place that is the algebraic sum of three consecutive volume changes, namely:

(1) A volume change due to liquid contraction.
(2) A volume change due to solidification contraction.
(3) A volume change due to solid contraction.

75. If the specific volumes of a metal are plotted as ordi-

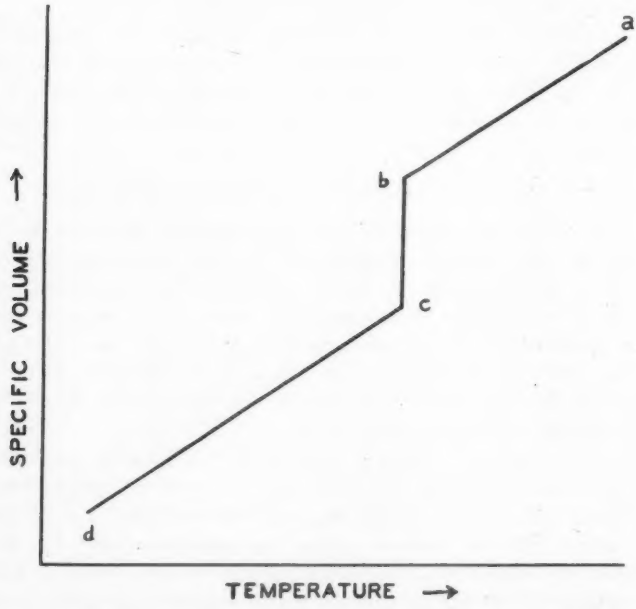

FIG. 4—TYPICAL SPECIFIC VOLUME-TEMPERATURE CURVE OF A METAL.

nates and the temperatures plotted as abscissae, these volume changes for a metal may be represented graphically.

Change in Specific Volume

76. In the sketch (Fig. 4) $a - b$ represents the change in specific volume with change in temperature of a metal in the liquid state as it cools from some temperature a to the freezing temperature b. The interval $b - c$ represents the change in volume of a metal in passing from all liquid metal at temperature b to all solid metal at temperature c. The interval $c - d$ represents the specific volume change of the solid metal as it cools from the freezing point c to room temperature d.

77. The per cent volume change for each stage can be calculated from the difference in specific volume for that particular stage, thus:

The per cent volume change due to the metal cooling from a to b is equal to the difference between the specific volumes represented by these two points divided by the specific volume at a times 100, or

Per cent volume change due to liquid contraction

$$= \frac{a - b}{a} \times 100.$$

Likewise, the per cent volume change due to solidification shrinkage $= \frac{b - c}{b} \times 100.$

and the per cent volume change due to solid contraction $= \frac{c - d}{c} \times 100.$

78. It is thus obvious that if the specific volume-temperature curves of the liquid and solid metal are known, the shrinkage due to solidification can be calculated from the difference between the liquid and solid specific volumes represented by the curves at the freezing point for a pure metal, or the difference between the specific volume of the liquid at the beginning of the freezing range and the specific volume of the solid at the end of the freezing range in the case of an alloy.

Dilatometric Methods for Specific Volume

79. Dilatometric methods for the determination of the

specific volume of liquid metal are limited to metals of low melting points for want of suitable refractories. These methods are applicable for the indirect determination of the specific volume-temperature curves for solid metals.

80. Buoyancy methods have been used to determine the change in specific volume of metals with change in temperature throughout the three types of volume change undergone by a metal in cooling from a temperature in the liquid state to a solid at room temperature. However, an error may be introduced in passing through the solidification range, due to the formation of internal shrinkage or gas cavities.

81. The pyknometer method used by Edwards for measuring the specific volume of liquid metals also was limited to metals of low melting points.

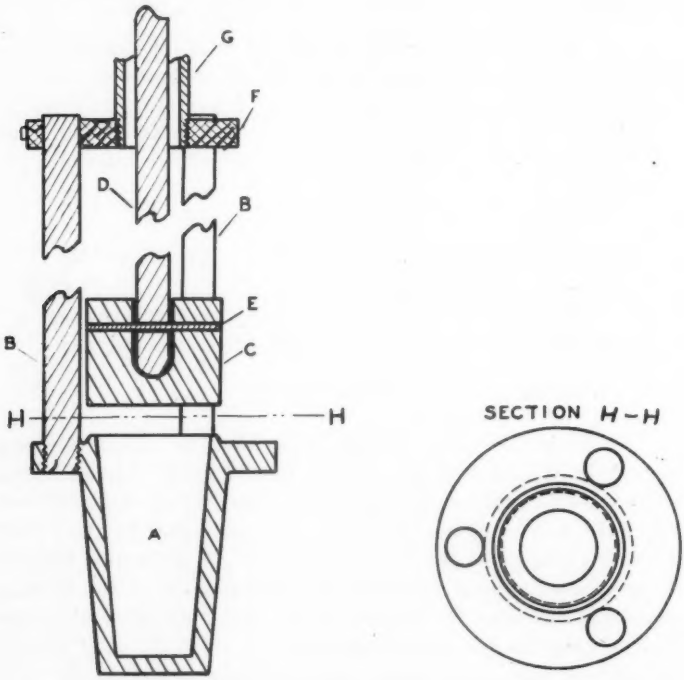

FIG. 5—SKETCH OF CRUCIBLE IMMERSION APPARATUS. *A:* CRUCIBLE. *B:* SUPPORT RODS. *C:* LID. *D:* CONTROL ROD. *E:* SUSTAINING PIN. *F:* METAL BASE. *G:* METAL HANDLE.

82. Sand-cast sphere, cone and cylinder methods could not be used to obtain data for constructing the specific volume-temperature curve, for reasons pointed out under the sand-cast cone method.

83. It seemed necessary, therefore, to find relatively simple methods that are applicable to wide ranges of temperature for determining the specific volume-temperature curves of metals.

Liquid Specific Volume-Temperature Curve

84. A method for determining the specific volume-temperature curves of metals in the liquid state has been developed which is relatively simple in manipulation and is applicable over a wide range of temperatures. A mass of liquid metal of known volume and at a definite and pre-determined temperature was isolated from a ladle of the metal under investigation. This

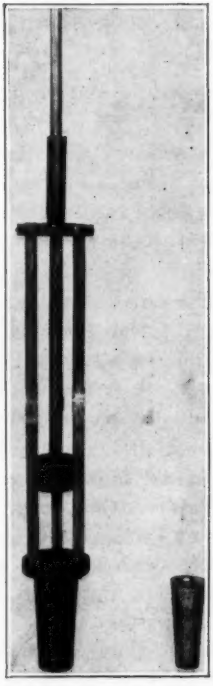

Fig. 6—Crucible Immersion Apparatus and Ingot

method, a variation of the pyknometer method, is termed the crucible immersion method.

85. The apparatus consists of a crucible supported by rods fastened to a metal base, which is in turn equipped with a metal handle. A lid operated by a control rod is suspended above the crucible (Figs. 5 and 6).

86. The crucible, lid and support rods are made of graphite for making measurements on metals that do not attack graphite. The dimensions of the crucible are arbitrary.

87. The volume of the crucible at room temperature is determined by weighing the mercury necessary to fill the crucible when the lid is pressed down firmly. The volume of the crucible at temperatures up to 600 degs. Cent. is calculated from the thermal expansion of graphite as given by Hidnert and Sweeney.[34] The volume at higher temperatures is obtained by extrapolation.

Extracting Known Volume of Liquid Metal

88. The procedure for extracting a known volume of liquid metal from a melt at a definite and predetermined temperature is as follows:

89. The crucible is filled by immersing it in a ladle of molten metal. Sufficient time is allowed for the crucible and metal to come to temperature equilibrium, or to allow them to cool down to the temperature at which it is desired to obtain a sample.

90. Temperature measurements are made by means of a thermocouple within a protection tube placed inside the crucible cavity. When the desired temperature is reached, the thermocouple and protection tube are removed, the lid is pressed down firmly on the crucible, and the whole assembly is removed from the ladle.

91. The sample of metal thus obtained is allowed to freeze and cool to room temperature. Obviously, the mass of the metal has not changed on cooling. The resulting ingot is weighed and, knowing the volume of the crucible, the specific volume of the metal at the temperature of sampling is calculated by dividing the volume of the crucible at that temperature by the weight of the ingot.

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[34] P. Hidnert and W. T. Sweeney, Technologic Papers, the Bureau of Standards, No. 335.

92. The curve representing the change in specific volume of the liquid metal with temperature change may be constructed from the values of the specific volumes of the metal at three or more different temperatures.

Factors in Applying Method to Iron

93. A graphite crucible cannot be used for obtaining samples of liquid iron because the iron reacts with the graphite, changing not only the dimensions of the crucible but also the composition of the iron.

94. Preliminary tests with mullite indicated that this refractory material is too sensitive to thermal shock and, therefore, is unsatisfactory for use in obtaining samples of liquid iron.

95. A protective coating on graphite has been produced which, from tests carried out thus far, makes the graphite non-oxidizing at high temperatures and inactive to molten cast iron. Several ingots of gray cast iron obtained in this manner readily separated from the crucible after cooling to room temperature. The crucible did not appear to have been attacked by iron.

Solid Specific Volume-Temperature Curve

96. In addition to determining the liquid specific volume-temperature curve, it is necessary to determine the solid specific volume-temperature curve for the metal under investigation in order to obtain the values for the solidification and solid shrinkage. Thermal expansion data for many pure metals are available in the literature, and can be used for determining the solid specific volume-temperature relations.

97. In the case of gray cast iron, the thermal expansion data obtained by heating a gray-iron casting would not give the specific volume-temperature relations necessary for calculating the above-named three types of shrinkage, because it is well known that heating a gray-iron casting results in permanent growth. It is necessary, therefore, to obtain the linear contraction data of the metal as it cools originally from the melt.

Gray Iron Affected by Graphite Separation

98. The dimensional changes in gray cast iron are affected by the separation of graphite. On freezing and during cooling, cast iron undergoes a partial transformation of cementite to

ferrite and graphite. Since the specific volume of graphite is approximately three times that of cementite, this transformation results in an increase in volume.

99. This volume increase varies with the amount of cementite decomposed and therefore is dependent on the following factors:

(1) The composition of the metal, inasmuch as total carbon, silicon, manganese, sulphur and phosphorus all affect the stability of cementite.

(2) The rate of cooling of the metal, since chilling tends to produce white iron, which is free from graphite, while slow cooling tends to produce gray iron.

100. Hence, the dimensional changes due to graphite separation are affected by everything that affects the cooling rate, i. e., pouring temperature, thermal conductivity of the mold and metal, temperature of the mold, size of casting (total heat content) and thickness of cross-section. No value for dimensional changes in the solid state can be given for a cast iron without specifying the composition with respect to total and combined carbon. The presence of undissolved graphite nuclei in the melt may also affect the separation of graphite.

Some Previous Work on Linear Shrinkage

101. Several investigators have attempted to determine the linear shrinkage of metals in cooling from the freezing point or end of the freezing range to room temperature, by observing the difference in length between the mold and the resulting casting. Anderson[17] found his results for the linear contraction of aluminum and many of its alloys varied, as follows:

102. Other conditions being equal, he found that

(1) the smaller the cross section of a cast bar of given length, the less the contraction;

(2) the greater the length for a given cross-section, the less the contraction;

(3) the contraction was less in chill molds than in sand-cast molds.

103. Anderson's maximum value for the linear contraction of commercial aluminum was 1.68 per cent of the length of the solid bar at the freezing point, whereas the value calculated from the thermal expansion measurements of material of the same purity is 1.85 per cent, as will be shown later.

104. Coleman,[35] working with a 90-per cent gold, 10-per cent copper alloy obtained a net casting shrinkage of 1.25 per cent, whereas the contraction of the solid metal was 1.62 per cent. Coleman suggested that the variation was probably due to stretching of the casting during cooling as a result of "hanging" to the mold wall or the feeding of metal during the cooling process.

105. Turner,[10] in measuring the total linear contraction of gray cast iron as it cooled from the end of the freezing range to room temperature, used a metal rod to join the movable end of his T bar casting with his measuring device or extensometer. One end of the metal connecting rod was necessarily embedded in the end of the cast metal bar. In this and subsequent work using this method, no corrections appear to have been made for the linear expansion of the metal connecting rod.

106. Turner and Murray[11] reported an expansion of pure aluminum during freezing. In the discussion of this paper, Rosenhain points out that "once the metal was solid, no doubt the instrument would respond with some considerable degree of accuracy to the expansions or contractions of the metal; but before some sort of more or less rigid connection had been established between the extensometer bar and the fixed pin in the molding flask, he (Rosenhain) could not see what necessary connections existed between the movements of the extensometer and any volume change."

107. In a similar discussion of a paper by Ewen and Turner,[12] Desch stated that he agreed that the volume would vary in proportion to the length after the bar was once solidified. He also suggested that any observed expansion during solidification may be due to crystal thrust.

Author's Experiments on Linear Contraction

108. The sketch and photograph shown in Figs. 7 and 8 represent the type of test bar and apparatus used in the present investigation for determining the linear contraction of a solid metal or alloy. In this apparatus the movable portion of the bar (that portion between the fixed pin and the end bearing the fused quartz rod) can be of any convenient length.

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[35] R. L. Coleman, *Physical Properties of Dental Materials (Gold Alloys and Accessory Materials)*. B. S. Jour. of Research, vol. 1, Dec., 1928. (R. P. No. 32).

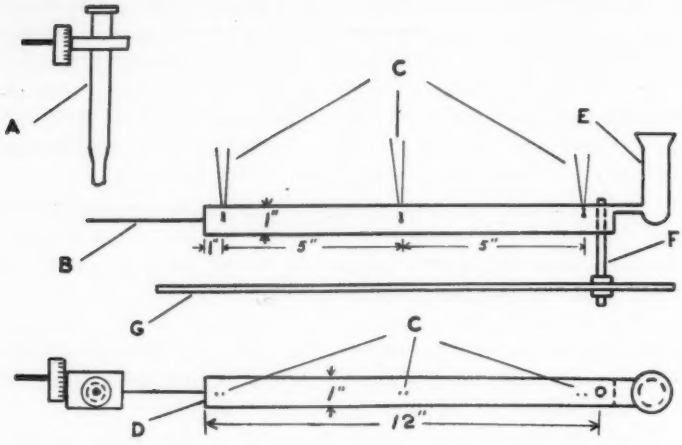

FIG. 7—SKETCH OF APPARATUS FOR MEASURING LINEAR CONTRACTION OF CAST METALS. *A:* MICROMETER MICROSCOPE. *B:* FUSED QUARTZ ROD. *C:* THERMOCOUPLES. *D:* SHRINKAGE BAR. *E:* POURING GATE. *F:* FIXED STEEL PIN. *G:* STEEL PLATE.

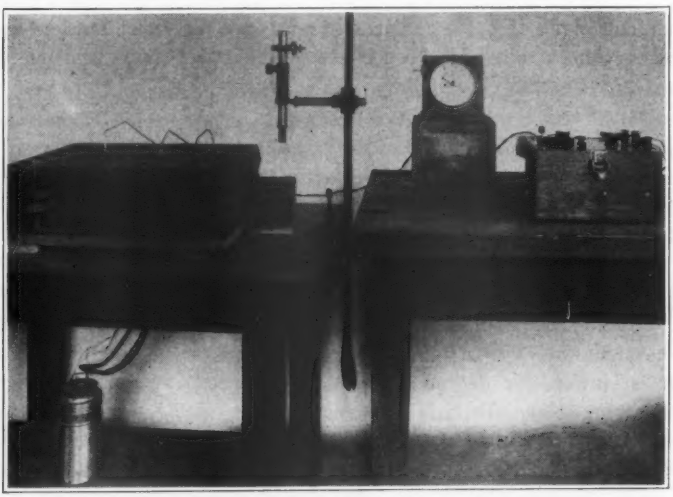

FIG. 8—APPARATUS FOR MEASURING LINEAR CONTRACTION OF CAST METALS.

109. A fused quartz rod is used to indicate the motion of the casting. The rod is allowed to project into the mold cavity one-eighth inch to insure that it shall be firmly gripped by the metal. The coefficient of thermal expansion of fused quartz is much less than that of iron, namely, 0.53×10^{-6} for fused quartz[36] and 14.7×16^{-6} for iron[37] (between room temperature and 600 degs. Cent.). A very small movement of the cast bar as transmitted through a fused quartz rod can be measured with the micrometer microscope. The mold is made of green sand.

Temperature Measurements

110. In order to plot the true temperature-contraction curve of any metal, it is essential that the average temperature of the bar be obtained during the cooling interval. For this purpose, three thermocouples are located in the 12-in. cast bar at distances of 1 in., 6 in. and 11 in., respectively, from the end of the bar bearing the fused quartz rod.

111. It is assumed that in this manner an average of these three temperature measurements represent the average temperature of the bar. In practice, these three thermocouples, all of the same length and size, are joined in parallel and the average reading of all three is obtained by one instrument.

112. Chromel-alumel thermocouples and a portable potentiometer indicator are used to indicate temperatures. The wires of the thermocouples are insulated from each other and from the molten metal by means of a sodium-silicate silica-flour cement. The welded tip of each thermocouple extends into the mold cavity one-half inch.

113. The procedure followed in a determination is as follows: Metal at a definite temperature is poured from a ladle into the green-sand mold. The temperature of the cast bar is recorded, the time at each observation being noted. The movement of the quartz rod observed through the micrometer microscope is recorded, together with the time of each reading, using the same timing device as in recording temperature changes.

114. The data thus obtained are plotted on a single chart, time being common to both temperature and contraction values. From these time-temperature and time-contraction curves, data are taken for constructing the temperature-contraction curve.

[36] W. Souder and P. Hidnert. B. S. Sci., Paper no. 524.
[37] W. Souder and P. Hidnert. B. S. Sci., Paper no. 433.

EXPERIMENTAL DATA

115. Specific volumes in the liquid state have been determined for a number of nonferrous metals using the crucible immersion method outlined in a previous section.

Specific Volumes of Liquid Aluminum

116. As an example of the computation involved, the specific volume of liquid aluminum is calculated from experimental data as in Table 2.

Table 2

CALCULATING THE SPECIFIC VOLUME OF LIQUID ALUMINUM

Temperature of liquid aluminum at time of sampling, degs. Cent.....770
Weight of aluminum ingot, grams.....160.99
Volume of graphite immersion crucible at 20 degs. Cent.....67.64 cm.³
Average cubical coefficient of expansion of graphite (20 to 770 degs. Cent.) .....10.6×10^{-6}
Total change in temperature of graphite crucible heated to sampling temperature (770 — 20 degs. Cent.), degs. Cent.....750
Volume change per cm.³ $(750 \times 10.6 \times 10^{-6})$.....0.0080
Volume increase for crucible (67.64×0.0080).....0.54 cm.³
Volume of crucible at 770 degs. Cent. (67.64×0.54).....68.18 cm.³
Specific volume of aluminum at 770 degs. Cent. $=$ Volume of liquid Al sample at 770 degs. Cent. / Weight of liquid Al sample at 770 degs. Cent. $=$ Vol. of graph. crucible at 770 degs. Cent. / Wt. of Al ingot at room temperature $=$ $\frac{68.18}{160.99} = 0.4235$ cm³ per gram.

117. In a similar manner, the specific volume of liquid aluminum was determined at 683, 727, 799 and 862 degs. Cent. These values of the specific volume of the liquid metal are plotted against the corresponding temperatures and a curve drawn through these points, which represents the change in specific volume of liquid aluminum with change in temperature.

Specific Volume of Solid Aluminum

118. The specific volume-temperature curve of solid aluminum from the freezing point to room temperature is determined in the following manner: Temperature and linear contraction

measurements are made on a cast bar during its period of cooling from the freezing point to room temperature. The time-temperature and time-contraction curves are then drawn.

119. Time is a co-ordinate common to both curves, so that for any given period of time, the contraction the bar has undergone corresponds to a definite temperature range. Fig. 9 gives time-temperature curves for the individual thermocouples in the bar, and also the time-contraction curve. In the general procedure, only the average temperature indicated by the three couples is plotted.

Linear Contraction-Temperature Curves for Aluminum and Cast Iron

120. Plotting the temperature and contraction values corresponding to a given time, linear contraction-temperature curves for aluminum and gray cast iron were obtained (Figs. 10 and 11). As may be observed from Fig. 10, this temperature-contraction curve tends to flatten out just below the melting point. This possibly is to be expected, since the cast bar may not be sufficiently rigid at this high temperature to register the true contrac-

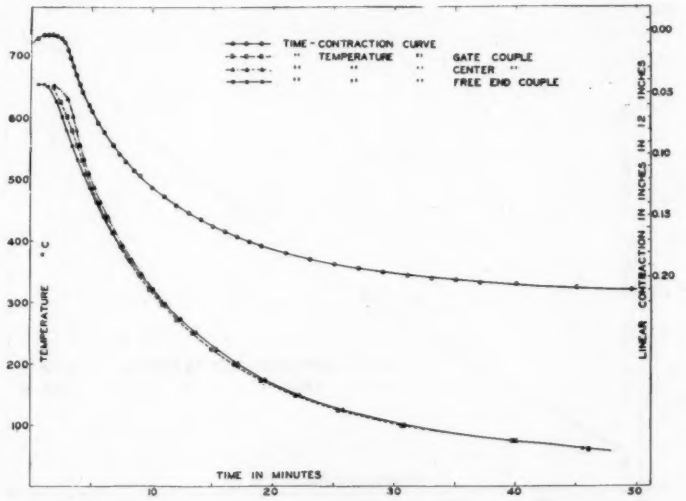

FIG. 9—TIME-TEMPERATURE AND TIME-LINEAR CONTRACTION CURVES OF COMMERCIAL ALUMINUM.

tion taking place. For the purposes of this investigation, this condition was met by extrapolating the main portion of the curve—evidently the true curve—to the melting point.

121. The total linear contraction of the bar from the melting point to room temperature, taken from the plotted curve and including the extrapolated portion, was 0.222 inches. The length of the bar at the melting point was 12 inches. Hence, the per cent linear contraction is

$$\frac{0.222}{12} \times 100 = 1.85 \text{ per cent.}$$

122. The cubical contraction of the metal may be taken as three times the linear contraction. Hence,

$$3 \times 1.85 = 5.55 \text{ per cent cubical contraction.}$$

123. The cubical contraction 5.55 per cent represents the decrease in volume undergone by aluminum in cooling from the freezing point to room temperature (20 degs. Cent.).

124. This value for the linear contraction of aluminum of this purity agrees closely with the linear contraction calculated,

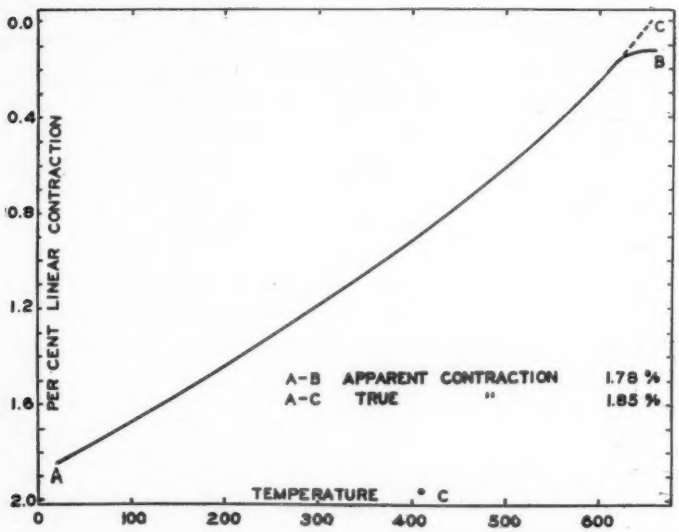

FIG. 10—LINEAR CONTRACTION-TEMPERATURE CURVE OF COMMERCIAL ALUMINUM.

by extrapolation, from the thermal expansion data given by Hidnert.[38]

125. The cross-sectional area of a cast bar of this aluminum was reduced in area 400 per cent by forging at 400 degs. Cent. The forged bar was annealed at 450 degs. Cent. for one hour. The specific volume of a sample cut from this bar was 0.3683 cm^3 per gram at 20 degs. Cent.

126. Since the volume contracted 5.55 per cent on cooling from the melting point at 658 degs. to 20 degs. Cent., then

(100 — 5.55) per cent = 0.3683 (spec. vol. at 20 degs. Cent.)

and

100 per cent = 0.3899 (spec. vol. at 658 degs. Cent.)

That is, the specific volume of aluminum in the solid state at 658 degs. Cent. is 0.3899 cm^3 per gram and is computed from the specific volume of the metal at 20 degs. Cent. and the contraction data obtained from the linear contraction measurements.

127. By extrapolating the curve representing the specific volume-temperature curve of liquid aluminum to the melting

[38] P. Hidnert, *Thermal Expansion of Aluminum and Various Important Aluminum Alloys.* B. S. Scl., Paper no. 497.

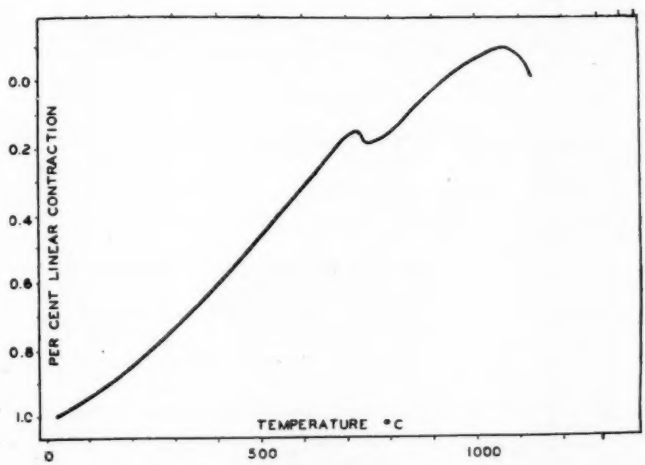

FIG. 11—LINEAR CONTRACTION TEMPERATURE CURVE OF A CAST IRON. ANALYSIS: COMBINED CARBON 0.57; GRAPHITIC CARBON 3.08; SILICON 2.27; MANGANESE 0.66; PHOSPHORUS 0.45; SULPHUR 0.04.

point (658 degs. Cent.), the specific volume of liquid aluminum at the freezing point is found to be 0.4173 cm^3 per gram.

128. The difference between the specific volumes of the solid and liquid aluminum at the melting point is the change in volume due to solidification shrinkage and is equal to

$$0.4173 - 0.3899 = 0.0274 \text{ cm}^3 \text{ per gram.}$$

129. Hence, the volume change undergone by aluminum in passing from liquid to solid at the freezing point, calculated with reference to the volume of the liquid at the freezing point, is

$$\frac{0.0274}{0.4173} \times 100 = 6.6 \text{ per cent.}$$

130. The specific volume-temperature curve for the aluminum in the solid state may also be computed from the coefficient of linear thermal expansion given in the literature. The average

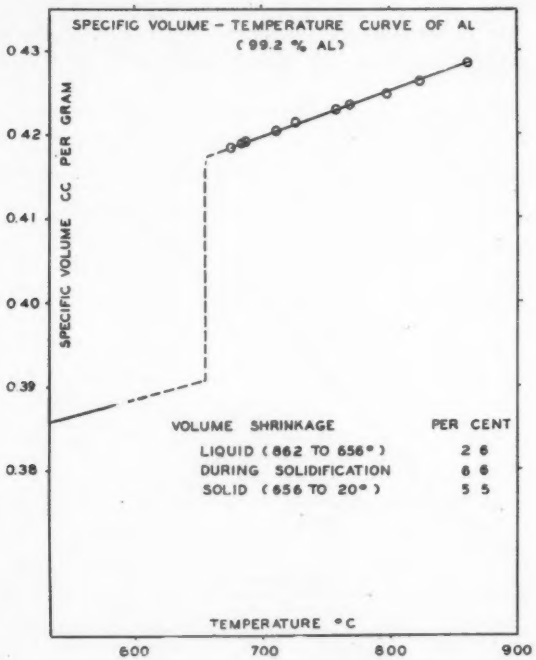

FIG. 12—SPECIFIC VOLUME-TEMPERATURE CURVE OF COMMERCIAL ALUMINUM.

linear coefficient of expansion of aluminum of this purity was determined by Hidnert[38] as 28.7×10^{-6} for the temperature range from 20 degs. to 600 degs. Cent. By extrapolating to 658 degs. Cent., the average coefficient of linear expansion for the temperature range 20 degs. to 658 degs. Cent. was found to be 29.0×10^{-6}.

131. This latter coefficient, multiplied by the difference in temperature times 100, gives the per cent linear contraction of this aluminum in passing from the freezing point at 658 degs. to 20 degs. Cent.:

$$29.0 \times 10^{-6} \times (658 - 20) \times 100 = 1.85 \text{ per cent.}$$

132. The value determined by the linear contraction of the cast bar coincides with this value. Calculation of the specific volume of the solid at the melting point is the same as was illustrated in a previous paragraph.

133. The specific volume-temperature curve of aluminum in the liquid state, and also a portion of the curve in the solid state, is shown in Fig. 12.

134. By an entirely similar procedure, specific volume-temperature curves have been determined for zinc, lead, tin and an 8-per cent copper-aluminum alloy. The curves for the solid specific volume of these metals have been computed from thermal expansion data taken from the literature. The curves for these metals are given in Figs. 13, 14, 15, and 16.

Table 3

SOLIDIFICATION AND SOLID SHRINKAGE OF SEVERAL NONFERROUS METALS

Metal.	Shrinkage during solidification. Per cent	Shrinkage from solidification to 20 degs. Cent.* Per cent
Commercial aluminum	6.6	5.5
Zinc	4.1	4.1
Lead	3.3	2.9
Tin	2.9	1.4
8 per cent copper-aluminum alloy	7.7	4.3

*The solid shrinkage was calculated from thermal expansion data from the following sources:

(a) Commercial Aluminum and Eight Per Cent Copper-Aluminum Alloy. P. Hidnert. *Thermal Expansion of Aluminum and Various Important Aluminum Alloys*, B. S. Sci., Paper no. 497.

(b) Zinc: Schulze. Physikalische Zeitschrift, vol. 22 (1921), p. 403.

(c) Lead: P. Hidnert and W. T. Sweeney, *Thermal Expansion of Lead*. Physical Review, vol. 35 (1930), p. 296.

(d) Tin: Cohen and Olei. Zeit. f. Phys. Chem., vol. 71 (1910), p. 385.

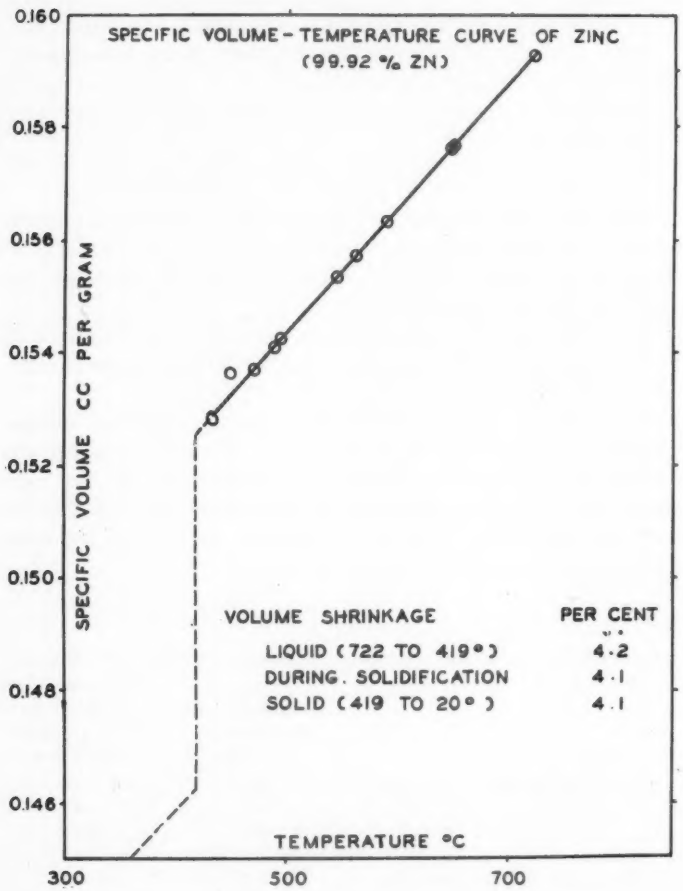

FIG. 13—SPECIFIC VOLUME-TEMPERATURE CURVE OF ZINC.

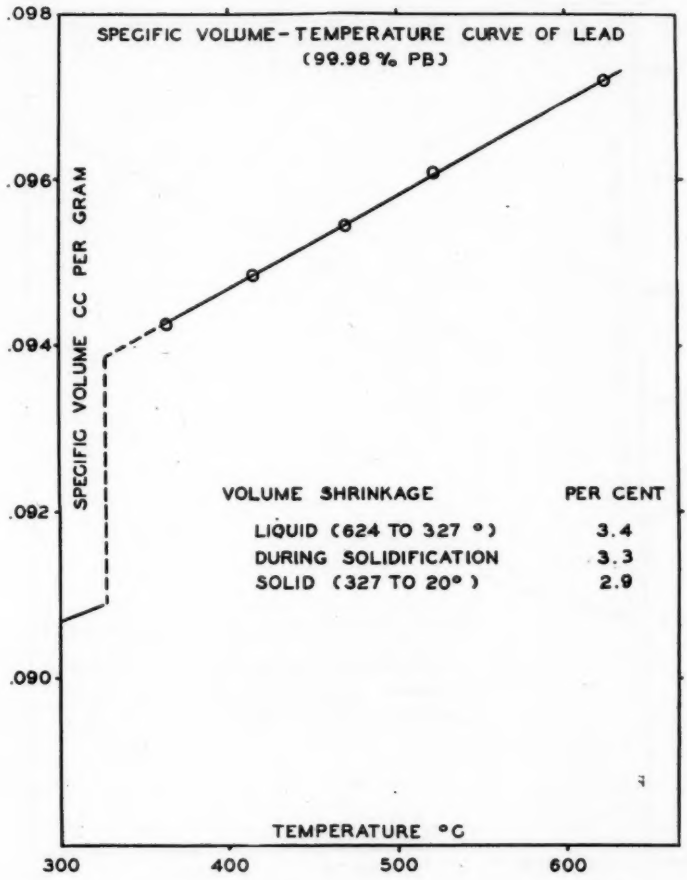

Fig. 14.—Specific Volume-Temperature Curve of Lead.

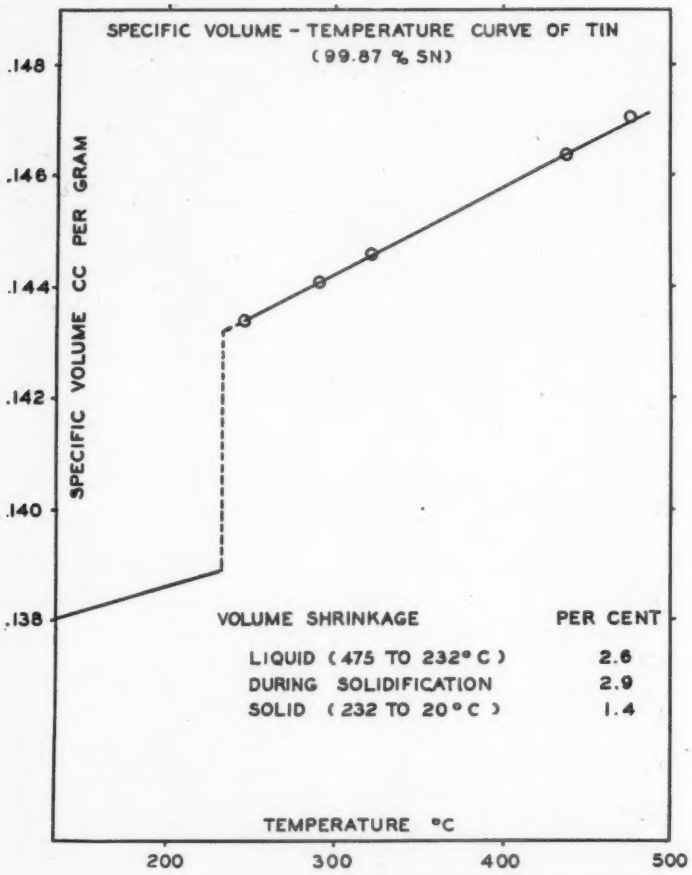

FIG. 15—SPECIFIC VOLUME-TEMPERATURE CURVE OF TIN.

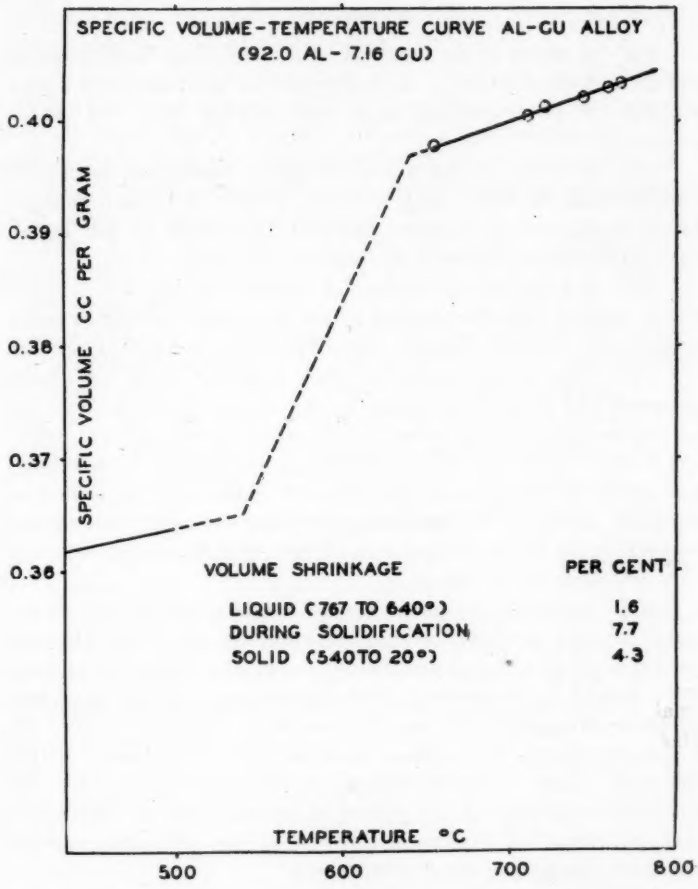

Fig. 16—Specific Volume-Temperature Curve of 8-Per Cent Copper-Aluminum Alloy.

Values for Solidification and Solid Shrinkage

135. Values for the solidification shrinkage and the solid shrinkage of these metals are given in Table 3.

SUMMARY

136. A study of the influence of the shrinkage undergone by metals and alloys during casting upon the production of sound castings of predetermined size was divided into two major phases:

(1) A study of the volume changes undergone by metals cooling from the liquid state to room temperature, such changes being considered as definite physical properties of the metal, quite apart from variables in foundry practice.

(2) A study of the relation of variables in foundry practice to the amount and distribution of the shrinkage cavities or other evidences of volume changes which remain in a finished casting.

137. The present paper reviews methods which have been proposed and used for determining the various types of shrinkage undergone by a cooling metal; defines the three types of shrinkage to be considered—liquid shrinkage, solidification shrinkage, and solid shrinkage, and considers in detail two experimental methods, namely, the sand-cast cone method and the method depending on the determination of the specific volume-temperature relations of the metal.

138. True shrinkage data were not obtained by use of the sand-cast-cone method, for the following reasons: (1) The temperature of the metal at the instant the mold cavity is completely filled cannot be determined, since there is no uniformity of temperature throughout the mass of metal in the mold cavity; (2) a volume change takes place in a portion of the metal within the mold cavity (due to chilling of the metal along the sand surfaces) even during the period of pouring the casting, and a certain amount of feeding of the casting has taken place before the mold cavity has filled with metal.

139. The second and more accurate experimental method is that which depends on the construction of the specific volume-temperature curve for the metal under consideration. The specific-volume temperature curve in the range of liquid metal—the liquid contraction curve—is constructed from data secured by application of the crucible immersion method, viz., by filling a

crucible of known volume with the liquid metal at known temperature.

140. The mass of the liquid metal at the temperature of filling the crucible is the same as the mass of the solidified contents of the crucible at room temperature. Hence, the liquid specific volume is readily calculated.

141. The curve in the range of solid metal—the solid contraction curve—is constructed from data given by direct observations of the change in length with change in temperature of a sand-cast bar of metal. The difference between the specific volume of the solid metal and of the liquid metal at the melting point is the solidification shrinkage.

142. In the case of an alloy, the solidification shrinkage is the difference in specific volume at the beginning and at the end of the freezing range.

143. Typical experimental data and calculations are given, and liquid and solidification shrinkage values are determined for commercial aluminum, an 8-per cent copper-aluminum alloy, lead, zinc and tin. In the case of commercial aluminum, the specific volume-temperature curve was also determined from a cast linear shrinkage bar.

Acknowledgments

144. The authors are indebted to a number of individuals of the Bureau staff for their cooperation in this investigation, especially to Louis Jordan for his suggestions, advice and constructive criticism; to L. D. Jones for preparing molds and castings; to E. L. Peffer for his work on density of the various specimens, and to Peter Hidnert for his valued criticism.

Steel Founding as It Is Practiced in Australian Plants*

By Daniel Clark, Newcastle, N. S. W., Australia

Abstract

After a review of the history of steel founding in Australia, the present industrial conditions affecting standardization of methods and wage payments are discussed. The basic wage in Australia is perhaps the highest in the world, because of labor governments having been largely in control. Apprentice training lasts for a five-year period.

All known processes of steel making are used, with the electric melting furnace supplanting the converter process. Due to the scarcity of low sulphur and low phosphorus scrap, the furnaces are basic lined. Lining mixtures are discussed. Pouring temperatures and melting temperatures are stated to have a great influence on casting quality.

Molding sand conditions are described as similar to those of the United States. Chemical and physical properties are discussed, the chemical analysis being considered of doubtful value. Comparisons of available sands are given. Green-sand and dry-sand molding are both used, the green-sand method being on the increase. Adequate venting is especially advocated.

The foundries of Australia are almost entirely engaged in jobbing work for mines, quarries, tramways and railroads.

1. Either on account of its remoteness from the great continents of the world, or (shall vials of wrath be poured upon our heads if it is suggested?) due to omissions in elementary school curriculums, a few misconceptions exist as to the size and potentialities of Australia. It may, therefore, occasion a degree of surprise when it is realized that the respective areas of Australia and the United States are almost equal—approximately 3,000,000 square miles.

2. Australia's population, exclusive of full-blood aborigi-

*Exchange paper, Bureau of Steel Manufacturers of Australia.

nals, is rather more than six and a quarter millions, 38 per cent of whom are resident in one state, *viz.*, New South Wales. The location of the greater number of the inhabitants is at or adjacent to the seaboard, and vast tracts in the interior are entirely unpeopled.

Supplies and Growth of the Industry

3. While lacking the magnificent, broad, inland rivers of the United States, so important in the economics of a nation, Australia is believed to contain vast stores of mineral wealth as yet unknown and untapped. The iron ore deposits within sight are sufficient for the needs of the steel industry for centuries ahead, and are of a quality unsurpassed in the world for the manufacture of the highest grade of basic open-hearth steel.

4. As a nation, it is yet in swaddling clothes and the steel industry little more than convalescing from the pains of birth. The steel foundry, with which it is our immediate attention to deal, was the first branch of the industry to be established in Australia. Its beginning was of a very modest character.

5. The pioneers were Smith, Phillips and Dawson, who commenced operations with a small crucible plant at Brunswick, a suburb of Melbourne, Victoria, in the year 1888. Later in the same year and, strangely coincident, also at Brunswick, Davies & Baird (who earlier had been producing iron castings for which they obtained an award at the Melbourne Exhibition in 1888) decided to enlarge their sphere of activities, and became competitors of the aforementioned trio in the field they had opened up.

Entrance of Bessemer Process

6. No further development took place until 1897, when a concern calling themselves The Steel Company of Australia put down a plant in Melbourne. Their melting unit was what was described as a continuous bessemer. Like the standard bessemer, the tuyeres were in the bottom of the vessel.

7. While occasionally fairly good steel was obtained, on the whole the process proved practically valueless for the regular production of steel of reasonable quality, and as often as not something approaching cast iron resulted. It might be observed, however, in parenthesis, that as fairly good steel was sometimes obtained, it would appear that the technique of the operation was not fully understood.

8. This company becoming financially embarrassed, its assets and liabilities were taken over by one James Martyn, who in 1906 installed a Tropenas converter. Lack of capital prevented him from procuring the proper plant for producing the blast, and he had to make shift with what he could find within his limited means. He was fortunate, however, in being able to purchase an old locomotive cheaply for the purpose of driving a Roots blower, and by this means provided the necessary air.

Electric Steel Making Begun

9. This probably represented the initial attempt to produce steel castings in Australia fulfilling the requirements of modern specifications. Until 1915 all castings were made by the crucible or converter processes, but that year saw the installation of the first electric unit for the Australian Electric Steel Co. in Sydney, New South Wales.

10. During the World war period, development accelerated due to supplies being difficult to procure, and the growth of the industry has since progressed along well-ordered lines. Proof of its expansion is found in the fact that 12,000 tons of steel castings were produced in Australia last year.

11. The geographical position of the continent and its isolation from the great manufacturing centers of the world make it necessary to become increasingly self-supporting. This fact has been recognized by successive governments, and a measure of support is given manufacturers by the erection of tariff barriers, when such can be done without unduly prejudicing the interests of the primary producers.

Railway Work Predominates

12. While railway and tramway work represents the major portion of the output, the fact that these services are state-owned, and are themselves laid out for fulfilling a not inconsiderable proportion of their requirements, forms a serious handicap to private enterprise.

13. Except under very special circumstances, no government department can successfully compete upon equal terms with privately owned concerns in Australia any more than they can elsewhere. This is true simply because the energizing spur of competition is absent, and there does not exist the same necessity to key up to the highest efficiency.

14. Privately owned railways in general recognize that if profits are to be earned one thing is vitally necessary, and that is to purchase the bulk of their requirements from specialists, not only because this is the policy economy dictates, but because they thus can be reasonably assured of quality and service.

Contact with Other Countries

15. That the steel industry in all its ramifications shall be efficient is the settled policy of the manufacturers, and close contact for that purpose is sedulously maintained by frequent visits of administrative and executive representatives to America

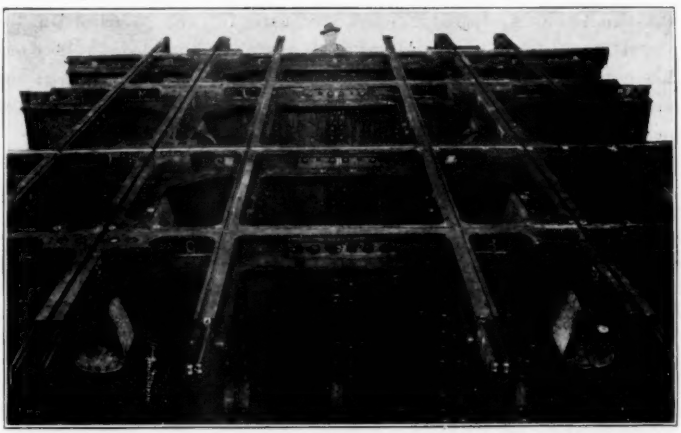

FIG. 1—MANGANESE TRACKWORK PRODUCED BY VICKERS-COMMONWEALTH STEEL PRODUCTS, LTD., WARATAH, N. S. W., FOR MELBOURNE METROPOLITAN TRAMWAYS. COMPLETE UNIT WEIGHS 17 TONS AND IS DESIGNED FOR BOTH CABLE AND ELECTRIC TRAMS. MADE UP OF 16 MANGANESE CROSSINGS MOUNTED ON FABRICATED STEEL STRUCTURE, RUNNING AND BEARING FACES COMPLETELY GROUND.

and Europe. More than this, their experiences are frequently pooled for the benefit of all.

16. This has been brought about through the instrumentality of the Bureau of Steel Manufacturers of Australia, a body formed primarily for the purpose of discussing manufacturing problems and promoting in general the best interests of the industry. Although only in existence since 1925, it has been of incalculable value, and the high efficiency the industry is fast attaining in every sphere is largely due to its efforts. Men of

vision and foresight were responsible for its inauguration, and they conferred a boon not only on the Industry *per se*, but, in a wider sense, upon the Commonwealth of Australia.

STANDARDIZATION

17. While the modern trend toward standardization is being followed, up to the present this has been mainly confined to quality and physical properties rather than seriously attempting to standardize production. As representing possibly the natural starting point, specifications covering railway requirements were the first to be formulated.

18. Unfortunately, however, and despite the circumstance that the various state railways are directly represented on the committees, some have introduced specifications of their own. This constitutes a handicap to manufacturers and strikes at the root of standardization with its attendant tendencies toward lower costs.

Comparison with American Position

19. The automobile industry in America, by standardization, mechanization and exploiting mass-production methods to the full, gave a fine lead to the iron and steel founders who, because of rapidly increasing markets, were compelled to seek all the aids that standardization and mechanical appliances could give. These, coupled with payment by results, have placed American manufacturers in a favorable position.

20. While such conditions do not yet exist in Australia, any more than they did in America at a similar stage of development, it is believed that the former will eventually occupy a position not less advantageous.

21. Piecework rates or bonus systems are taboo in most trades in Australia, due to the parochial outlook of the strongly entrenched trade unions. An additional and serious handicap is the existence of a 44-hour working week. While most employers in these days are sympathetic toward the employed in every legitimate effort to improve their conditions, they feel that they also have moral claims for consideration, one of which is that they are entitled to a fair return for money invested.

Basic Wage Is High

22. By comparison, the basic wage in Australia is perhaps the highest in the world. Not content with this, however, efforts

are being made to increase it by still further reducing the hours to 40 per week. In common with those countries engaged in the World war, Australia has incurred an enormous debt. Bearing this in mind, employers may surely be pardoned for stating emphatically that a young country such as this, now only in the process of development, cannot afford further flights in the realms of socialistic experiment.

23. Nor can it continue to have laboring conditions so much in advance of those obtaining in most other countries of the world, unless production is equal (which is impossible).

24. Successive labor governments have so pampered labor in the urban areas that rural workers have migrated thither and created a shortage on the land. The perpetuation of a policy like this does not generally make for the ultimate prosperity of any country, and there seems no reason for believing that Australia will be the exception.

FOUNDRY APPRENTICE TRAINING

25. Boys commence their apprenticeship at the age of 16. The duration of their service is five years, commencing on the core bench, thence to the various molding machines and finally on floor work. Although it is not compulsory, they are expected to attend the technical school, where they are taught the following subjects:

Practical molding.
Theory.
Trade calculations.
Drawing.

26. Upon exhibiting a certain proficiency in their studies, their technical education is paid for by their employers, and a record is kept of the progress of each boy for the purpose of review when promotions are being considered.

27. Close observation has shown generally that when an apprentice becomes careless in his studies as represented by his college reports, his work in the foundry suffers in like manner. The problem of technical training of apprentices is of vital importance, and it is held that the extent to which this is exploited will govern definitely the growth and efficiency of the industry in Australia.

28. One disability some non-technically trained molders suffer from is that they are not adept at reading drawings. In

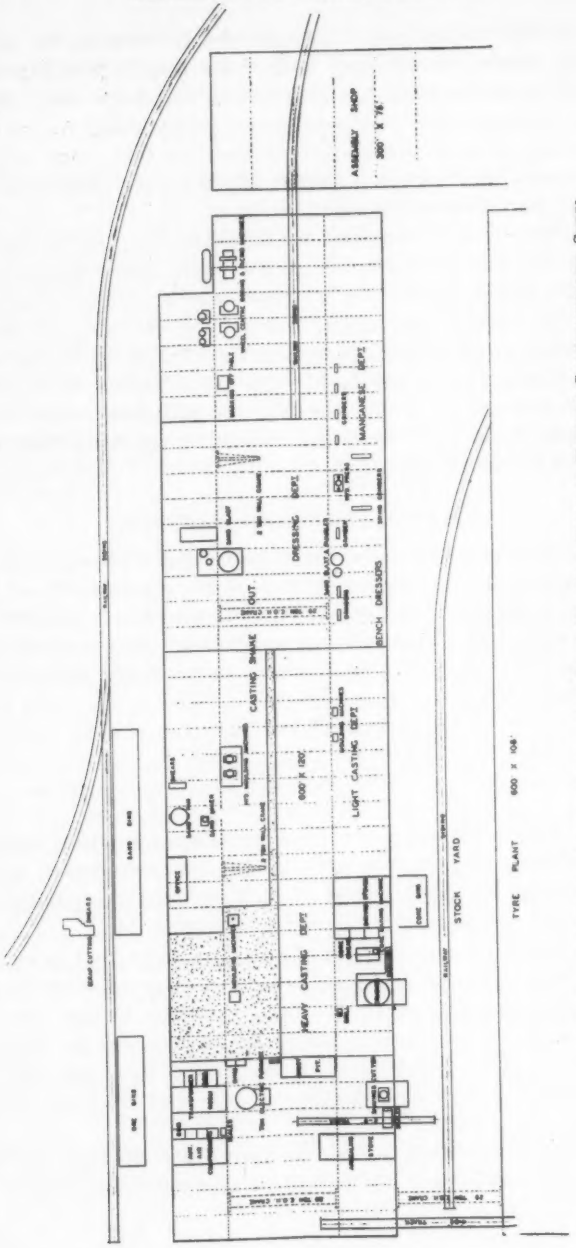

FIG. 2—LAYOUT OF A TYPICAL AUSTRALIAN STEEL FOUNDRY, THAT OF VICKERS-COMMONWEALTH STEEL PRODUCTS, LTD., WARATAH, N. S. W.

jobbing shops doing a large variety of work this constitutes a real handicap, and too much responsibility is thereby thrown on to the patternmaker.

Steel Making

29. All known processes of manufacturing steel are in vogue for the production of castings. Two plants only make open-hearth steel, namely, The Broken Hill Pty. Co., Limited, and The Australian Iron & Steel Co., Limited, both of whose works are in New South Wales. Either plant is capable of producing castings on a large scale, but as they possess various rolling mills and large blast-furnace units, the bulk of their foundry production is intended solely for their own consumption, rather than the open market.

Electric Furnace Superseding Converter

30. Despite the undoubted advantages of the Tropenas converter for foundry purposes, it is being gradually replaced by the electric furnace, which method is capable of producing steel second only to crucible in quality. In most of the foundries operating the electric process, in winter the steel is made during the night for the purpose of evening the load line at the power stations, and as a consequence concessions to users are made.

31. There are certain disadvantages arising from night melting, one of which is the fact that the molds fashioned during the day have to lie a considerable length of time before being filled. At all times this is found to be disadvantageous for green work, and in times of high atmospheric humidity, equally so for dry work.

32. The type of electric furnace mainly in use is the 3-phase 6-ton Heroult with 115 volts and 7000 amperes at 25 cycles. The electrodes are 10-in. graphite. The electric supply is obtained from the government station at 6600 volts through a transformer of 1500 kilovolt-amperes capacity.

Basic Steel Principal Product

33. Due to the scarcity of low sulphur and phosphorus scrap the furnaces are basic lined. It is usual to build with magnesite bricks from the bottom to two courses above the breast plates, then a course of chrome bricks with the upper portion and roof of silica bricks or special firebricks.

34. Electrode holders and frames of charging and tapping

doors are water cooled. The bottom and banks are made up of magnesite, chrome ore and slag mixed with hot anhydrous tar, and rammed with hot compressed-air rammers.

35. Two methods are employed in sintering the hearth, one by burning in the magnesite with coke and broken electrodes, the other by running a small high-carbon heat from specially selected scrap. The latter is quite successful if done carefully, and it saves time. Bottom and bank repairs during the run of the furnace are effected by using dolomite.

Charging Procedure

36. In charging, the heavier scrap is first placed in position, then the turnings and on top, foundry scrap in the form of risers and runners. Limestone is added with the charge in lump form, but is crushed for use during the refining period. When surging is heavy, as happens when the charge contains an undue proportion of heavy scrap, the electrodes are controlled by hand until normal conditions prevail.

37. The whole of the center of the charge is allowed to melt and become thoroughly hot before attempting to push into the pool the scrap lying around the doors and banks. This increases the speed of working and causes less damage to the furnace banks.

38. When the charge is completely melted, the furnace is tilted forward slightly and the slag run off, a green sapling being used to drive it from the back to the spout. The refining slag is then added and the heat carried to completion in the usual manner.

Pouring Temperature Effect

39. No phase in the production of steel castings demands more attention than the question of temperature of the steel at pouring. With so many variables entering into the problem, the solution is not always easy. In deciding upon the temperature to aim for, the analysis of the steel and the number and nature of the jobs to be cast must be considered.

40. No scientific means of estimating the temperature of the steel before leaving the furnace has proved more reliable, in the writer's opinion, than the old practical method of estimating the time taken for a spoonful of metal to scum over, or, alternatively, from pouring a spoon sample on the floor. Due to the facility with which energy can be provided, electric steel

is found liable to greater temperature variations from heat to heat than that steel made by any other process.

41. While it is common practice to hold the steel in the ladle for a time when poured too hot, it is a matter for speculation whether steel so treated is not already spoiled and can ever be expected to meet the most exacting tests.

42. It will be conceded without dispute that, in the final heat treatment, the finest structure is obtained when the critical point has just been passed, and that increasing increments of temperature beyond that coarsens the grain and detrimentally affects the physical properties. In other words, the grain size obtained is that represented by the maximum temperature reached.

Critical Temperature for Steel

43. Bearing this in mind, is it too much to assume that there is also a critical temperature for molten steel, and that when once this is exceeded, its quality is impaired?

44. Concerning the problem of temperature at the point of casting, take the case of Hadfield's high-manganese steel. This is a steel which the practical foundryman knows to have an inherently high degree of fluidity. Despite that, it is frequently found too hot both in the furnace and the ladle, with a consequent loss in the efficiency of the ferroalloy additions.

Life of Casting Is Final Test

45. More important than the latter, however, is the quality of the finished product. If cast at varying temperatures, it will be found that the length of the chill crystals formed on the skin of the casting varies with the temperature, being largest when this is highest. It will also be found in the extreme cases that this structure is so persistent that the subsequent standard toughening treatment will fail to remove it.

46. Assuming, then, that we have a casting exhibiting the latter characteristics, and which is subjected to severe bending moment, there is every probability of such fracturing readily, due to the fact that the formation of a crack or cracks is rendered easy at the junction of adjacent crystals and parallel to the major axis. The speed at which cracks grow arising from this cause will depend upon the length of the chill crystals, and their progress will only be retarded at the point where the chill crystals merge into the normal fibrous structure.

47. It is not difficult, then, to foresee that a casting operating under the condition described, particularly one of thin section and poured at an excessive temperature, is likely to have a short life.

Why Do Steels Fail?

48. While the phase just discussed concerns casting temperature only, which is always controllable to some extent, there is yet the other aspect mentioned, which is directly associated with the furnace operation and which is probably more vital in all steels irrespective of analysis, and more difficult to determine.

49. Instances are not lacking—particularly with high-grade steels designed to meet the more difficult specifications—where test or service failures definitely cannot be traced to faulty fabrication, heat treatment or analysis, nor anything which the microscope can reveal after the most minute search. It is possible that the explanation of such failures lies in the fact that there is a definite loss in the properties of a cast of steel when a certain critical temperature has been passed in its manufacture, no matter by what process.

50. In the production of castings it is probable that some of the losses due to contraction cracks or excessive brittleness are attributable to this. A heat of steel behaving thus abnormally may be truthfully described as having a disease for which there are known palliatives but no absolute cure, and it would appear as if a fruitful field exists for extensive research in this direction.

MOLDING SAND

51. In so far as natural sand deposits are concerned, the general conditions in Australia are somewhat analogous to those obtaining in America, in that suitable sands regular in quality do not appear to exist near enough the various foundries nor in sufficient quantities to warrant their exploitation. We do not, therefore, occupy the fortunate position of the British and European foundries, most of which have excellent natural sands within easy reach that can be obtained cheaply and worked up at little cost.

52. In regard to analysis, the closest approach to the famous Mons deposit in Belgium thus far found in Australia was at Wyee, situated on the main line between Sydney and Newcastle, New South Wales. This sand was tested and com-

pared with the Belgian sand—both in the laboratory and on a practical scale in the foundry—by Vickers-Commonwealth Steel Products Limited, of Waratah, New South Wales.

53. The respective analyses found are shown in Table 1.

Analysis of Australian Sand

54. The strength of the Wyee sand was excellent, judged by the overhanging test, the results obtained showing 4⅜ in., against 4 in. in the case of the Belgian sand. Comparative sieving tests revealed the Belgian sand to be finer, but under the microscope the grains were found to be somewhat similar in shape.

Table 1

COMPARATIVE ANALYSES OF AUSTRALIAN WITH BELGIAN SAND

	Belgian Per Cent	Wyee Per Cent
Silica	91.87	93.13
Oxide of iron	2.21	1.14
Alumina	3.02	3.58
Titanic oxide	.29	.21
Lime	.51	.07
Magnesia	.41	.03
Loss on heating	1.95	2.13
	100.26	100.29

55. From the standpoint of analysis and bond strength, it might reasonably be assumed that the Wyee sand was superior to the Belgian, but the practical results in the foundry did not bear this out. Castings of superior finish were obtained from the latter sand.

56. It would thus appear that analysis alone is not sufficient to enable the suitability of sands to be forecasted, but that the real factor is the form in which the elements exist. Moreover, natural sands, unless in exceptionally fortunate circumstances, are apt to vary in composition at changing depths and on this account require scrupulous supervision.

57. The Wyee sand referred to is a case in point. The analysis quoted was that obtained when the sand was first tried in 1927, but results obtained at lower stratas proved the silica to have dropped to 72.26 per cent.

Sand Strength Test Questionable

58. The remark may be here interposed, on the question of sand analysis, that this is a tedious and costly determination,

and it is doubtful whether its value is commensurate with the expense or the time spent on it. The chemical analysis is primarily a guide to refractoriness, while the alumina may be regarded to a certain extent as a measure of the clay and bonding power.

59. It is suggested that the fusion test is really the better index of the refractory value and—combined with a fineness test to indicate permeability and a bond test to gauge strength—enables the foundryman to quickly determine the quality of any sand.

60. Recently another deposit has been found near Newcastle, N.S.W., which shows early promise. The analysis is shown in Table 2.

61. Whether this sand will fulfill all the requirements has yet to be proved, but it is the general tendency to irregularity in natural sands that has compelled Australian foundries to adopt, for the most part, synthetic sands using as the basis a high-grade silica rock or wind-blown beach sand.

Investigation of Sand Practice

62. Recognizing the important part that molding sands play in the success of the foundries, and so that effort would be coordinated in investigational work, the Bureau of Steel Manu-

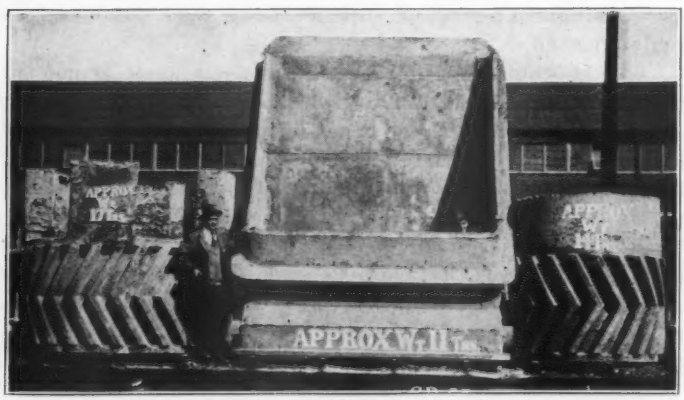

FIG. 3—EXAMPLES OF CASTINGS PRODUCED BY THE BROKEN HILL PROPRIETARY CO., LTD., NEWCASTLE, N. S. W.

facturers of Australia, New South Wales state division, appointed a research committee to investigate the problem. The objects of the research were:

1—To investigate sands at present in use.

2—To explore new deposits.

3—To lay down standard methods of testing.

Table 2

CHEMICAL ANALYSIS OF AN AUSTRALIAN SAND

Silica, per cent	89.40
Oxide of iron, per cent	1.49
Alumina, per cent	6.21
Magnesia, per cent	0.10
Alkalies, per cent	0.08
Loss on ignition, per cent	2.68
Fusion point, degs. Cent	1737 (3140 Fahr.)

FINENESS TEST

Screen mesh size	8	20	40	60	80	100	100+	Clay
Remaining on screen, per cent	None	0.10	5.9	56.6	12.8	4.9	5.0	14.7

Moisture, per cent	6.6
Permeability	205
Green strength, lbs	3.1
Dry strength, lbs	8.5

NOTE.—These tests were made on the A. F. A. permeability and bond strength machines.

Questionnaire on Foundry Sands

63. As a preliminary step in the work, the committee formulated a questionnaire which was circulated among the foundries of the state, and replies to the following queries were invited:

1—The source of your molding sand.

2—Method of preparation.

(a) Type of mill.

(b) Time of milling.

(c) Do you riddle after milling? If so, why?

3—Composition of your facing sand for green and dry sand work in

(a) light castings

(b) medium castings

(c) heavy castings

4—Moisture content you have found to produce the best results.

5—The composition of your backing sand.

6—The composition of your core sand.

7—Type of melting unit.

8—Do you use a mold face wash? If so, what do you use, and why?

Summary of the Replies Received

1—Three distinct types of sand are in use:

(a) Wind-blown beach sand.
(b) A natural red sand.
(c) Friable sandstone, commonly referred to as "rotten rock."

The latter type predominates, but any of the three forms the basis of all steel facing sands used in this state.

2—All prepare their sands in mills, the type only differing in that some have revolving pans while others are fixed. One firm, preparatory to milling, pass their rotten rock through a jaw crusher and crush to about ¾ in. or less. The times of milling range from 5 to 12 minutes. With regard to sieving, all the replies except one stated that this was done to separate hard, uncrushed nodules. The exception was a firm using sea sand, and sifting in their case was only adopted to break up and aerate the sand.

3—Generally, about 50 per cent of returned sand is incorporated in the facing mixture. The thickness of the facing sand used is fairly consistent at from ¾ to 1 in. for light castings, 1 to 1½ in. for medium castings and 2 in. or over for heavy castings, depending on the size and design.

4—For dry-sand work the figures run from 5 to 7 per cent; for green work, 3 per cent is stated.

5—As backing sand, returned facing sand is for the most part used.

6—For small cores, facing sand is generally used; for medium and heavy cores, oil sand.

7—The melting units are open hearth and electric only.

8—All replies indicate that silica face wash is used, first, to improve the appearance of the skin of the casting, and second, to increase the refractoriness of the mold faces.

PHYSICAL TESTING OF SANDS

64. When the research committee commenced work, it was found that no uniform system of physical testing was in vogue, the figures obtained by any one company having, therefore, only a limited value. The committee thereupon investigated the question of suitable standard forms of tests to be applied, and decided that, as the research committee appointed by the American Foundrymen's Association appeared to have done more in the matter of standard routine tests than had been done elsewhere, their methods and equipment should be adopted.

65. Samples of sand were obtained from the various companies represented on the committee, together with several other deposits within easy reach, and the following investigations carried out:

1—Chemical analysis.
2—Fineness test.
3—Bond strength with varying moistures.
4—Permeability.
5—Grain shape.

Sands Examined

66. The particulars of the various sands dealt with by the committee were as follows:

No. 1—Friable sandstone from quarry at Tempe, near Sydney.

No. 2—Sydney district sandstone from local building excavations.

No. 3—Sydney district sand.

No. 4—Marangaroo sand from Lithgow district.

No. 5—Botany sea sand.

No. 6—Wyee sand.

No. 7—Belmont sea sand from a beach deposit near Lake Macquarie.

No. 8—Hawksbury sandstone from building stone quarry, near Gosford—bottom strata.

No. 9—Hawksbury sandstone from building stone quarry, near Gosford—middle strata.

No. 10—Hawksbury sandstone from building stone quarry, near Gosford—top strata.

No. 11—Belgian sand—imported.

Table 3

CHEMICAL ANALYSIS OF SOME SANDS USED IN AUSTRALIAN FOUNDRIES

No. and Origin	SiO_2 Per Cent	Fe_2O_3 Per Cent	Al_2O_3 Per Cent	CaO Per Cent	MgO Per Cent	TiO_2 Per Cent	Alkalies Per Cent	Ignition Loss Per Cent
1. Tempe sand	93.25	1.44	3.64	0.10	0.05	....	0.53	1.00
2. Sydney district sandstone	90.96	0.24	5.88	Trace	0.48	0.35	0.46	1.47
3. Sydney district sandstone	93.60	0.79	3.61	Trace	0.28	0.05	0.42	1.16
4. Marangaroo sand	....	....	....	....	....	....	....	....
5. Botany sea sand	97.60	0.20	1.48	0.08	Trace	....	0.13	0.59
6. Wyee sand	79.72	3.84	10.90	Trace	0.22	....	0.11	4.97
7. Belmont sand	97.36	0.31	1.58	....	0.18	....	0.08	0.42
8. Hawksbury stone, bottom strata	82.54	3.27	9.14	....	0.22	....	1.62	3.05
9. Same, middle strata	77.90	1.40	13.16	0.38	0.50	....	1.99	4.28
10. Same, top strata	81.58	3.59	9.31	0.18	0.22	....	1.78	3.05
11. Belgian sand, imported	92.80	1.02	4.02	Trace	Trace	Trace	0.32	1.66

67. All of the sands mentioned above, with the exception of Nos. 8, 9, 10 and 11, were being used by various steel foundries in this state. The analyses obtained are shown in Table 3.

Fineness Tests Performed

68. Acting on the supposition that the ideal sand should have the largest amount possible remaining on a 60-mesh sieve, the order of merit of the sands tested, by remainder percentages, was as follows:

	Per Cent
1. Botany sea sand	80.0
2. Belmont sea sand	78.0
3. Tempe sand	67.5
4. Marangaroo	48.0
5. Gosford Rock—middle strata	45.5
6. Gosford Rock—top strata	41.0
7. Gosford Rock—bottom strata	29.0
8. Wyee sand	22.5
9. Belgian sand	5.5

69. Remaining on 100 mesh, the order of remainder percentages was as follows:

	Per Cent
1. Belmont sea sand	99.0
2. Botany sea sand	98.0
3. Tempe sand	75.5
4. Gosford rock—middle strata	73.5
5. Gosford rock—top strata	68.0
6. Marangaroo	61.0
7. Gosford rock—bottom strata	59.0
8. Belgian sand	57.0
9. Wyee sand	31.5

What Tests Developed

70. Reviewing these results, the outstanding features are:

1—The uniformity of grain size of the Belmont and Botany sea sands.

2—The comparative fineness of the Belgian sand.

3—The similarity among the rotten rocks from Tempe and Gosford.

Trend Toward Synthetic Sands

71. While the whole question of facing sands is still *sub judice,* the indications definitely are that synthetic sands make for greater reliability in properties and results. From a refractory point of view, the best base undoubtedly is well-weathered wind-blown sea sand, but the difficulty of finding a suitable binder that will be cheap, and of such a nature that will ensure each individual grain being coated, is not readily surmountable.

72. The remedy seems to lie in using a naturally bonded sand as the basis and increasing its refractoriness by incorporating a certain amount of sea sand or river gravel. This not only provides a sand of the requisite strength and refractoriness, but the same strict attention to milling does not appear necessary. It is along these lines that Australian foundries believe their sand problems are capable of solution.

73. While the greater percentage of castings produced in Australia are of the dry-sand type, the amount of green-sand work is steadily increasing. Important as the temperature of the steel undoubtedly is for the successful production of dry-sand work, it is perhaps more so for green sand.

74. It is found that, except for small work or where very thin sections are concerned, the best green work is obtained when the temperature is at its lowest, say, toward the end of the run and after the dry-sand molds have been filled. Satisfactory green-sand castings are not only being produced on products of thin section where little or no machining is required, but on fairly large, heavily proportioned castings requiring a considerable amount of machining.

75. There is more than a little diversity of opinion as to the relative merits of dry and green-sand molds in the production of, for example, railway wheel centers. The protagonists of dry-sand work assert that it is not possible to consistently

produce green-sand castings free from the subcutaneous blowholes sometimes disclosed when machining the surface of the rim.

Realize Importance of Venting

76. There appears no doubt, however—with the advent of more efficient methods of sand control, a keener appreciation of the benefits of systematic venting and a realization of the important part that condition and temperature of the steel itself play in this problem—but that the latter method will be much more extensively adopted.

Types of Work Produced

77. As has been indicated, Australian steel foundries are almost entirely engaged on jobbing work, and it is the belief based on observations abroad that on work of a general character the standard will bear comparison with that obtained elsewhere.

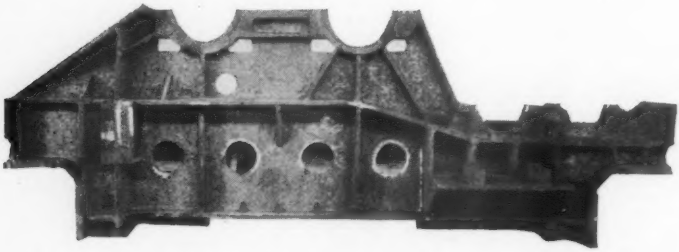

FIG. 4—CRANE-CRADLE CASTING PRODUCED BY VICKERS-COMMONWEALTH STEEL PRODUCTS, LTD., WARATAH, N. S. W.

78. Indicative of the general types of castings produced by hand molding are the following:

Mining—Haulage wheels, liners, gear wheels, etc.

Quarries—Excavator replacements, bucket teeth, rock-crushing machinery, roller shells, pathway plates, etc.

Tramways—Special trackwork, manganese steel switches and crossings.

Railways—Locomotive wheel centers; carriage and wagon castings, such as bolsters, side frames, etc.

Machine Molding in Wide Use

79. As to machine molding, while a large number of miscellaneous carriage and wagon castings—such as axle boxes, side frames, etc., and colliery skip wheels—are made in this manner, the preponderance of machine work is represented by carriage and wagon-wheel centers. Jolt, ram and turnover machines are in general use, although the smallest wheel centers are being made on hydraulic squeeze machines. The machines are usually served by a crew of three, including a molder, a laborer and a finisher.

Gates and Risers

80. With regard to the casting of wheel centers and the like, the horn type of runner entering at the underside of the boss has given complete satisfaction in some plants. Its position readily permits removal and in no way interferes with the machined surfaces.

81. This runner allows the use of full-sized risers of the enclosed type, but at the cost of reduced metal recovery. Most plants, however, favor the open-half riser which also serves as the pouring point for the metal. This method is simpler and has the advantage of yielding a higher recovery.

82. Nevertheless, there are disadvantages, among which is the greater risk of causing erosion of the mold, consequent upon the fall of the metal on the sand face. This is liable to produce sand pockets, which may result in increased dressing and higher machining costs. When the erosion is severe, the free sand so displaced generally becomes entrapped under the ledge forming the boss face diametrically opposite the riser.

83. Concerning the full head, the main disabilities arising from this lie not only in the reduced metal recovery but also in the increased cost of its removal and the necessity for a larger core. On the other hand, in addition to the comparative freedom from sand on the boss face, the enclosed head improves the feeding properties by retarding the freezing of the metal. It also eliminates the necessity for utilizing studs for the purpose of centralizing the core, and in lieu thereof a core print on the cope is provided.

Removal of Gases

84. Referring now to the question of venting, it would appear that this aspect is deserving of greater attention than it

receives generally, and is capable of more intelligent application. Consideration of the physical conditions prevailing within a mold, from the first entry of the metal to ultimate solidification, reveals several problems upon the successful solution of which depends to some extent the quality of the foundry product.

85. Apart from contraction—to minimize which effect the steel molder has to allow for the natural shrinkage if tearing is to be avoided—there is the matter of providing for the removal of gases that may be evolved from the sand or metal, and in addition, the displacement of air within the mold. The elimination of these baneful but unavoidable elements not only requires consideration of the influence of design and the positioning of risers but also the important part that venting plays.

86. The gases liberated earliest tend to collect at points of minimum pressure and maximum temperature, which in the latter case will be where the section is greatest. It is for that reason that the experienced molder will always place the heaviest section at the lowest position in the mold whenever possible, and will provide adequate risers suitably positioned and designed to ensure not only the maximum pressure but also the elimination of gases and contained air.

Opinion on Mold Surfaces

87. Reverting now to the surfaces of the castings, it is probable that the gas from the mold itself is liberated before the maximum evolution from the metal commences, and that it occurs when the latter is in a weak condition. Hence it is evident that, unless the facing sand is sufficiently permeable and unless ample artificial vents are provided to ensure the unrestricted passage of air and gas from the sand when the pressure is at the maximum, part is liable to pass into the steel, producing an unfavorable condition likely to be accentuated later when the gas given up by the metal comes into play.

88. In the case of plate work particularly, it is necessary to have the facing sand highly permeable and, furthermore, to provide all the vent holes possible in the backing sand. Otherwise, the production of castings free from gas holes and surface blemishes is found to be impossible.

89. The molds for all castings with large flat surfaces should be amply vented from the inside with a small wire or rod, then carefully finished.

Necessity of Proper Venting

90. Except in limited instances, steel molders generally have a certain lack of appreciation of the efficacy of adequate venting, and a failure to grasp the fact that a number of strategically or wisely placed vent holes bring their reward in the shape of better quality castings with fewer surface defects disclosed on machining. Any cases where venting is apparently ineffective can usually be traced to lack of care in leading off the vents, as blind or choked vents may easily produce a condition more unfavorable than their complete absence.

91. There is yet another undesirable condition which may exist within the mold, namely, that resulting from a high total moisture in the sand. In such a case the steam and gases evolved may cause a reaction sufficiently violent to destroy the more delicate parts of the mold, the consequence of which is to produce sand accumulations or sand holes mainly at or near the upper faces of the casting.

92. To avoid faulty castings arising from this source, it is found necessary to keep a close check on the moisture content of the sand from day to day.

Annealing Practice

93. Concerning annealing practice, some Australian foundries favor oil-fired furnaces with the double truck. When handling castings of a general character, the idle truck is fully charged and run in when the truck load under heat is withdrawn.

94. The full annealing temperature in the furnace is maintained all the time, and departure from this procedure is only made when castings of intricate design are involved. In such cases they are allowed to cool off slowly in the furnace.

95. While this paper is intended mainly as a general outline of the activities and practice obtaining in Australian steel foundries, it is hoped that it is sufficiently adequate to convey some idea of the rise and increasing importance of the foundry industry in Australia. If the author has successfully fulfilled this condition, then he will be amply repaid for any trouble he has taken.

Materials Handling and Storage in Foundry Operations

By W. M. Booth, Syracuse, N. Y.

Abstract

Three general rules for improving materials handling in the foundry are: General use of electricity or mechanical power; routing work through plant in as nearly a straight line as possible; waist-high movement of all materials involving labor. In some departments of author's company, use of these rules has eliminated or reduced greatly hand-labor operations. Plant conditions govern the extent to which mechanical devices may replace manual labor economically. Handling raw materials and equipment—pig iron, scrap, coke, molding and core sands, cores, patterns, flasks, etc.—from stock storage yard to cupola are discussed. Opinions of coke manufacturers are given on how coke should be handled. Necessity of mechanical devices in foundry increases as melt exceeds 30 tons per run. Northern foundries, due to climatic conditions, should have under-cover storage, and storage bins on cupola floors, holding at least two days' supply of all charging materials. Materials should flow by gravity from bins well above charging floor into charging buckets whenever possible. Continuous molding and pouring is said to reduce floor area needed from 50 to 75 per cent, and divorcing molders from all other duties increases their output greatly. Three methods of transferring iron to molds are given: (1) Small ladles to act as shuttles between mixing ladle and mold; (2) ladles of several hundred pounds to serve smaller ladles; (3) pouring from cupola ladle direct to molds. Comparisons of materials handling costs are given.

1. Under this title our message to foundrymen covers a broad field. To be of general assistance, many details must be omitted. The small jobbing foundry does not lend itself to mechanical handling such as is the case with huge automobile or machinery-casting plants. However, the foundry manager, no matter how small or large his business, will admit that im-

provements may be brought about in connection with his operations after systematic study.

2. We have three suggestions to offer this foundry business, none of them new or difficult to comprehend or adopt: First, general use of electric or mechanical power; second, routing work in as nearly a straight line as possible through the plant, and third, waist-high movement of all materials upon which labor is expended.

Mechanical Power

3. The kilowatt hour is approximately 1⅓ horsepower. A manpower, as defined by the Standard dictionary, is one-tenth of a horsepower. In terms of the electric unit, a manpower is, then, about one-thirteenth of a kilowatt.

4. The latter may be purchased in many localities for 1.5c, or 12c for an 8-hour day. On the same basis, a man-power day is one-thirteenth of 12c, or about 1c. At this ratio man cannot compete with electricity. We should employ workmen to use intelligence rather than muscular force.

5. Electricity, easily managed, handles our materials cheaply to any limit we choose to employ. The question of its adaptability to certain operations opens a field for study, while the use of expensive handling equipment increases overhead expense. With the cheapest and most accessible power known to the human race, the manufacturers of today must determine how laborers or mechanics can be employed to the best advantage, while movement of materials is saddled upon the shoulders of power-producing specialists.

6. Vertical movement of materials is more cheaply handled mechanically. Horizontal movements may be divided among laborers and power-driven apparatus, depending upon the size of the load and the distance to be moved.

General Use by Industry

7. With these preliminary remarks, we will now turn our attention to materials-handling problems of the foundry. In so doing we follow the lead of the metal production business generally—a large tonnage, straight-line movement and the use of power wherever possible. In many departments of our blast furnace and steel plants laborers are no longer necessary and in others the payroll has been reduced 25 to 75 per cent.

8. Mechanical handling of materials in the foundry has

been practiced to a certain degree ever since castings have been produced. The crane and molding machine are generally used. Bench molding is an attempt to apply the waist-high theory to facilitate work.

MISCELLANEOUS MOVEMENT OF MATERIALS

9. Next to the primary mechanical machines, the simplest and most useful devices for the transportation of materials over short distances are the two-wheeled truck and wheelbarrow.

10. In the latter time-honored device, a couple of hundred pounds of iron, sand or castings may be wheeled at a speed of about two miles per hour. In many cases the unloading problem may be reduced to a simple dumping operation. If the workman is paid 50c per hour, he may move a fifth of a ton one mile at a cost of 50 cents, or at the rate of $2.50 per ton-mile.

11. We find wheelbarrows universally used in the smaller foundries. For any considerable tonnage this method of handling is expensive, and usually the runway is very irregular, vertically and horizontally.

12. A wheelbarrow is not safe or stable enough for the transfer of pig iron or castings in quantity, hence the use of a two-wheeled barrow, four-wheeled car or truck. The wheels must be strong and cast with wide rims that will not break under a heavy load. The easier these are made to run upon their bearings, the better. We usually cast these wheels from a good semi-steel mixture in the foundry and have the trucks made up either in the carpenter shop or locally.

13. For the quick handling of castings directly or in metal barrels with side lugs, the two-wheeled shipping truck or an adaptation of this occupies the foremost place. A smooth and strong floor should be provided.

14. Beginning with these simple and inexpensive transportation media, we cite the whole modern and very efficient series of carts, trucks, cranes, monorails and industrial railways of a score of varieties. Indeed, the transportation of materials is now of such importance and magnitude that we may purchase the truck that best fits our needs—manual or electric, lift, hoist, transfer, side or end dump or multiple tray.

15. If we have a unit load greater than 400 or 500 lbs., it has been our experience power of some sort should be employed to transport materials. Electric lift trucks leave nothing to be

desired for many foundry operations. They will carry heavy loads, may be operated with trailers, are free from fire risks and can be operated by one man, who need not be paid expert wages. Roller conveyors are inexpensive to install, are operated manually or by power, and are capable of handling loads to five or more tons.

16. Every foundry, large or small, has materials-handling problems to solve. How shall stock be loaded economically? What method of transportation is best? Having finished the journey, how shall the stock be unloaded and piled or stored with the least manual labor?

17. A large modern foundry may be classed as a complicated transportation problem which should be treated as a separate department, and often it is so considered. We suggest that one man shall be charged in every foundry organization with the movement of materials expeditiously and economically. Such a department may include a number of assistants. Materials movement generally is worked out much more readily in large than in small foundries.

Effect of Climate on Materials Handling

18. The climatic factor must be considered in connection with any materials handling problem. We will not undertake to designate any geographic area that requires special attention because of heat, cold, excessive humidity, frost, rain, snow or ice, for these conditions are well understood locally and can be studied accordingly. In central New York, for instance, we have suffered from frosted core and molding sand and from wet snow and ice-coated coke and iron.

19. We should not ask men or women to make cores from ice-cold sand. Furthermore, if snow or ice are present in the sand, a large loss may result from deformed cores. Coke, the voids of which are filled with water, makes a poor fuel; and snow or ice-coated iron cannot be handled safely, nor can it be weighed accurately.

20. For any foundry, large or small, sufficient under-cover storage should be maintained to eliminate excessive cold and moisture from sand of all varieties, and from stock used in the cupola. Sand may be stored in bins or sheds and should be brought to a temperature of at least 60 degrees before cores are made.

21. Coke and iron may be elevated to the charging floor at least two days in advance of use, where it should be piled in a dry place. The larger the foundry, the more serious this excess moisture problem becomes.

ROADS AND RUNWAYS

22. Nearly all foundries, particularly the older ones, show a startling lack of attention to suitable floors, roads and runways upon which employees may work and over which raw and finished stock may be carted or otherwise transported. Labor of handling is rapidly increased by an insecure footing.

23. Rankine states the resistance over gravel to be twice —and over sand, five times—that of a smooth stone road. Macadam or concrete roads should serve the foundry yard for unloading both incoming and outgoing freight and express by rail or by truck. No good excuse can be offered for poor roads. Where differences in level occur between floors, well-built ramps are very satisfactory.

THE FOUNDRY YARD

24. The small foundry is often operated without a formal stock-storage yard. The very compactness of the place may lend to economical handling of materials. Iron, coke and sand are moved by hand or with a wheelbarrow or carts a distance of a few feet only. Even this establishment can be improved by study and the time of handling materials may be reduced.

25. At the other extreme is the large business served by a yard covering several acres. Sand and iron are received and stored hundreds of feet from the cupola or molding floors. A switching engine (standard gauge or narrow-gauge railway) is kept busy daily hauling stock. The electric trolley may be used economically here.

26. The most modern storage yard is compact, does not contain miscellaneous junk and ancient equipment, is adjacent to the foundry, is provided with a railway siding and is served by a crane capable of movement over every portion of the yard where incoming and outgoing materials are stored.

27. The stock yard should be a well-drained, solid and level piece of ground. Upon this pig iron, sand, supplies and in some instances finished castings are to be located according to a systematic scheme, with a view to economy in handling.

Iron and Scrap Storage

28. A car of pig iron containing 50 or more tons is shipped from Buffalo to Syracuse, N. Y., a distance of about 150 miles, at an approximate cost of $1.80 per ton, or around $90 a car. The transportation cost of a long ton of iron for a mile is then 1.2c. When received in the yard, it may be unloaded and transported 75 feet and piled by four men in one-half day at an approximate cost (price of Northern labor) of $8, or a yard movement of $11.26 per ton-mile. No mass movement of materials in or about the foundry can compete with the railroad.

29. Where a foundry yard is served by an electric crane, iron is usually removed from the car by a magnet. Substantially constructed storage bins may be used instead of conical piles. These may be arranged parallel to the railway siding. They should be 25 to 30 feet from front to back, of equal width and deep enough to hold several cars of iron. The foundation must be very secure.

30. Materials of construction may be wood or concrete. We have found that wooden timbers a foot square give satisfactory service. These timbers may be covered with heavy sheet iron. The front wall of the bins may be a few feet lower than the rear and each bin is securely tied to its neighbor.

31. Shipments of iron, the silicon analyses of which do not differ by more than 0.10 per cent, may be placed in the same bin, provided the balance of the analysis is practically the same. Ample storage is provided in a similar manner for scrap, sand and limestone. The number of bins is determined by the different types of material.

32. Pig iron should be stored according to such a system that the distance traveled when iron is unloaded, or is collected and taken to the cupola, will be the least possible. Hence the importance of locating incoming freight near the part of the foundry from which materials are to be used.

33. We prefer a roadway through the center of the yard rather than at one side. As indicated before, this should be constructed of macadam or concrete upon which carts may be run with ease and certainty. A charge of 500 to 2000 lbs. of pig iron may be overturned with disastrous results.

34. In a number of instances we have systematized yard storage by asking for a regular method of piling iron in cord

fashion, two or more piles per carload, with a stenciled analysis board on the end of each pile—stenciled side down, protected from the weather and held in place by a pig of iron.

35. The foreman in charge of this operation must be experienced in piling machine and sand-cast pigs. Both are difficult to arrange in this way. The cupola helpers are often in danger from falling iron and are sometimes seriously injured.

36. The collection of iron from such piles becomes a dangerous operation when ice and snow cement the pigs to a solid mass. Where fifty to one hundred tons of iron are used daily, miscellaneous spreading of iron upon the ground leads to mistakes in car numbers, litters the yard and, in the case of manual collection, requires stooping to raise each pig to the carts. We prefer piling iron if it cannot be handled mechanically, but shall be glad to hear of better methods.

COKE

37. Coke has the disadvantage of being fragile. In the form of dust it has no value in the cupola, will not hold the burden of iron and blows out of the stack. Every effort must be made in unloading and handling to prevent losses of this character, which may approximate fifty cents or more per ton.

38. While large interests unload iron with a magnet, charge by electric cranes and run continuous pour, successful and efficient coke-handling often remains a partially solved problem. The conditions most desired are direct movement of coke from the car to the cupola, and the conditions least desirable are unloading on the railway track level, piling by hand, loading into carts, dumping these in front of the cupola and charging by hand.

Views on Coke Handling

39. Large producers and users of coke have kindly offered their experience in connection with this paper. We tabulate these:

40. "We believe that coke should be handled upon cotton or rubber belts. Where the vertical distances are greater, the skip hoist can be employed with the least loss."

41. "I might explain to you that the coke which is brought into our plant in drop bottom cars is dropped from the

cars through a trestle to a cement basement underneath. This, of course, does not necessitate any handling whatever.

"The tracks are inclined and hold about two carloads of coke between each support of the railroad track. This coke is then put into a Gardner drop-bottom bucket, holding one charge of coke for each charge of iron. This bucket is then picked up on a Sprague monorail hoist and delivered to the crane, which picks it up and drops it into the cupola.

"The only shoveling of coke which we have is in putting it into the bucket at the storage pile. We have found through this method that we break very little coke, whereas in the former way of forking it around we were losing approximately five per cent of the coke, in what we call breeze or dust, from breakage.

"I know of no other place that we have visited in our research where the coke is weighed accurately and delivered to the cupola with as little expense in handling. One man loads all the buckets on the ground and one man in the incline delivers it into the cupola. The coke is weighed on the charging floor on a Toledo automatic scale."

42. "I am enclosing a sketch of the plan view of our cupola-charging platform which shows our method of unloading and handling coke. The charging platform is about 20 feet above the yard level. On its west side are the limestone and coke bins. Through the center of the platform and along the east side are bins for pig iron and scrap.

"A gravity conveyor runs along the two sides and north end of the platform. Running over the top and extending beyond the north end of the platform is an 80-foot yard crane. A railroad siding runs along the north end of the building at ground level. Under the track at the north end of the building is a coke pit. The pit is divided by a wall into two parts. Coke is received in bottom dump cars.

"When the cars are to be unloaded, one is run over the pit, the bottom dropped and the coke goes into the chute on the south side of the pit. Two bottom-dump coke buckets, which hold about 800 lbs. each, are then lowered into the shaft at the north side of the pit and filled with coke by opening the gates. They are then raised one at a time and dumped into the coke bins on the charging platform. It takes three laborers and

the crane operator about three hours to unload a 30-ton car.

"When the coke is to be charged into the cupola, it is forked from the bin into the bottom of the charging bucket. The charging bucket moves by gravity over the roller conveyor and the required amounts of pig iron and scrap are added. When it reaches the end of the conveyor at the east side of the platform, it is picked up by the cupola charger and dumped into the cupola."

43. "Regarding my ideas along the line of handling coke from the car into the cupola, since we have just finished a new addition—which includes a coke-handling system for the old and new foundries—and as I had my choice of the various methods, I still think that the system we adopted is one of the most satisfactory for our type of foundry.

"The system consists of a track hopper with a skip hoist which lifts the coke up to the top of the cupola building, where it is dumped into an electric lorry which, in turn, distributes the coke into a series of bins immediately back of the cupolas and above the charging floor. Immediately back of the cupolas is an overhead charging crane which receives the coke and the limestone from these hoppers, weighs it and deposits it into the cupola.

"This system has been in operation for almost a year, and we have found it economical and satisfactory in every way, so that at this stage I would again install this system without any change."

44. "You understand, of course, that in our several plants we have various methods of handling coke, due to varying local conditions. In our continuous-pouring foundries, the most satisfactory method seems to be to take the coke out of side-dump or hopper-bottom cars with a belt conveyor, arranging the conveyor so that the unloading end delivers the coke directly into the charging bucket. The charging bucket, of course, is handled with an electric hoist and the coke charged directly into the cupola therefrom.

"For our own purposes we have found this to be the most economical and satisfactory method of handling coke, inasmuch as it tends to reduce breakage and fines in the coke.

"The coke is dumped into a track hopper directly from the car and is conveyed from this point by a 48 in. wide

apron conveyor 7 ft. 6 in. long onto a 24 in. fabric belt conveyor 40 ft. long into an 18 in. bucket elevator approximately 70 ft. high onto a 24 in. distributing belt into a 400-ton storage bin, located directly over the charging floor, and is dumped through hoppers into charging buckets."

Consensus of Opinion

45. Our experience and the experience of others seems to indicate the necessity of receiving coke in side or bottom dump cars. Space should be provided at the unloading point with about ten or twelve feet of clearance below the track. This is accomplished by elevating the track or by building coke-receiving hoppers below the track. From these hoppers with side doors, several hundred pounds of coke may flow by gravity into a skip hoist, by means of which it is elevated to ample bins one floor above the charging platform. By gravity it flows or is raked into the charging bucket.

46. A few foundry plants are melting sufficient iron to make possible the unloading of the materials constituting the charge directly from the cars to the cupola. This approaches the ideal.

47. If coke is received under a roof in a northern location, or in the open yard of a southern foundry, it may be transferred directly from the track hoppers to the charging bucket. The completed charge is then raised to the cupola floor and is released in the cupola itself.

PREPARING THE CHARGE

48. Our next problem is to bring the iron and fuel to the cupola to be charged. Under a very unscientific system, iron, scrap and coke are raised to the cupola floor and are dumped or piled about the cupola shaft. None of these materials is weighed; a good guess is made of quantities of each ingredient to be used. These are forked or thrown into the cupola. We realize that an experienced foreman on the charging floor may thus produce very good iron, but he always runs a risk.

49. A second and better method of charging employs an accurate scale upon which iron, sprues, scrap and coke are weighed. Sprues and scrap of all grades are raised to the cupola charging floor in heavy sheet-iron cans holding about 300 lbs. each. These cans have the tare stamped into the metal. The

weight of the contents is chalked upon the outside of each can.

50. Upon a blackboard the foreman writes the charge for the day. All metal and coke are weighed and loaded into the cupola by a system found to produce satisfactory iron. We have had excellent results through the use of such a system.

51. If more than 30 tons of metal are melted at each run, mechanical devices may be used to good advantage. In very large operations mechanical charging becomes necessary. Iron may be weighed into the charging bucket with the coke, i.e., the charge may be made upon the ground and lifted to and into the cupola.

Climatic Conditions Considered

52. Where climatic changes are not prohibitive for such an operation, we can see no reason for complaint. Northern locations, however, can be served better in this particular by making the cupola floor large enough to include storage bins for all materials used in the charge. In this case a yard crane elevates stock to bins running parallel to the storage yard, each provided with the bottom sloping toward the center of the building. In front of this bin system runs a trolley which consists of a flat-bottomed car, large enough to carry scales, and at least two charging buckets—one empty and returned and one filled.

53. By means of long-handled rakes or hooks the charge is drawn into the bucket—iron, scrap, limestone and coke. The electric hoist is very efficient in lifting the charge bucket, transferring it to the cupola and lowering it within. The weight of the charge should fall upon the metal below and not against or upon the walls themselves. While mechanical charging is a difficult operation, we feel this element of modern foundry control has been well worked out.

SAND STORAGE

54. Excepting in the largest and best-equipped foundries, sand is stored in piles. The work is done by men with shovels, or by power with clam-shell buckets. Sand is handled mechanically at a fraction of the cost of hand labor.

55. Modern core and molding sand storage methods employ concrete bins. These bins are often built with the wall lengthwise of the foundry, serving the inside wall of the bin itself. Such bins are in use 200 or 300 feet in length, 40 feet high and from 15 to 20 feet in width.

56. However, under-cover storage is needed by the small

and medium-sized foundry just as much as by the larger operations. The latter are served by an electric hoist to unload sand from the cars. At the base of several of these bins we have found an open door through which sand is removed in carts to the core room or molding floors.

57. Let us take the core sand first. The bottom of the bin should be slightly hopper-shaped and should lead directly into the mixer or muller—there should be two of these. The core oil is added here. This may be compounded in a tank serving both mixers and so situated that oils and other ingredients may be fed first to the oil mixer.

Core Oil Mixing

58. The mechanically operated foundry may well include a core-oil compounding or mixing plant. The adoption of such a process insures a core oil of uniform composition. The necessary apparatus consists of two oil-receiving tanks of at least tank-car capacity each. Suitable pumps are required to connect the raw materials supply with a mixing tank in which one batch of core oil may be produced at a time. This may cover requirements for one day, one week or one month.

59. The mixing tank is provided with a heating coil and draw-off valves. The tank should be connected with a receiving tank that supplies the oil directly to the sand mixers. A smaller tank and float valve may be arranged to draw the required amount of oil by operation of a hand lever. We have used such a system successfully for several years.

A Core Sand Problem

60. After riddling, the core sand is elevated to such a degree that the batch may be dropped to wheelbarrows, carts or upon a conveyor. We have a problem here, as linseed core oils sweat and stick, particularly in hot weather. For this reason few installations have been made that handle core sand wholly by mechanical means, that is, by belts. The sand must in some way be carried to the core -makers' benches or machines or both. The hopper above the core maker must deliver sand with ease.

61. Just how to distribute this sand is a question but the problem is solved in some plants, partially at least, by the use of a traveling belt or by a man with a wheelbarrow delivering core sand one floor above the core maker, through hoppers to the benches below. The cores are placed upon trays and may be

carried to a central station by the core maker. Preferably these cores are collected by boys or are placed upon some form of conveyor to take them to the ovens. *Core makers should be divorced from every other task.*

62. The oven itself may be vertical or horizontal and it may be electric, gas, oil or coke fired. The most desirable oven admits the cores at one end and delivers them uniformly baked at the other. Preferably, the carts carrying the green cores should be run into the oven. When the process has been completed they may be rolled into the foundry where they are stored or distributed.

63. If this happens to be a continuous-pour foundry, each molder may receive his cores by a roller conveyor sloping toward him, returning the empty trays to runways sloping outward from him. If the foundry is of the ordinary type, these cores are distributed in the usual way—to each molder.

HANDLING MOLDING SAND

64. The unloading and storage of core and molding sands are identical problems. Hopper-bottom bins are provided adjacent to the foundry. From these, sand is carted to the separate floors—in the case of a continuous-pour foundry, to the sand makeup of the system.

65. The use of machines to cut and mix sand is very general. We emphasize the importance of systematic daily riddling to remove rust, dirt and gravel from the sand mixture. This process is preferably handled by power machines. Thoroughly mixing air with sand is very desirable.

Confine Molder to Molding

66. The molder in any type of foundry should be relieved as far as possible from all labor excepting that of making his molds and setting his cores. Sand should be supplied through a hopper from the floor above. Mechanical devices should be provided to aerate, riddle and elevate sand to the hopper. The spill from the molding operation may be allowed to fall through a grate upon a simple elevator, where it joins the main supply.

67. Because a molder is a specialist, he commands high wages. Mechanical power and cheaper labor thus should be used wherever possible to supplement his efforts. It is not necessary in many jobbing foundries to install continuous-molding equipment, but we feel that all foundry managers should consider the

advisability of mechanical elevation and mixing of sand with a gravity supply to each bench or machine. The two- or three-story foundry may work out very successfully in connection with sand and castings movement by gravity.

68. Large flasks require such a volume of sand that a greater velocity is desirable than may be obtained by gravity. This has led to the introduction of a mechanically forced or driven molding-sand supply of the "slinger" type. The design of this machine has been one of the most difficult problems of the foundry engineer. Yet they are used to good advantage in increasing numbers yearly.

Patterns and Flasks

69. Patterns represent a large overhead expense. They are usually numbered, catalogued and stored with care upon suitable shelves in fireproof buildings. Such storage should be adjacent to the molding floor and as near as safety from fire will allow. The services of one or more men within closed gates should be employed in checking patterns and pattern plates in and out.

70. Baseboards and miscellaneous supplies may be kept in separate rooms adjacent to pattern storage. If the foundry is handling small work exclusively, a traveling belt may run between the pattern and stores rooms and the foundry. A medium-sized foundry usually occupies the time of from one to three men hurrying between the place where patterns are stored and where they are used—much of this is lost motion.

Air and Ventilation

71. Air occupies an important place in foundry affairs. It is used in the blast, on the molding machines, in power lifts, in hammers, and in cleaning castings, and is the medium that makes ventilation possible.

72. Cupola blowers, power compressors and molding machines have been developed to a high state of efficiency. The foundry owner is to be congratulated that so much ingenuity has been combined in these machines to simplify his problems.

73. Proper foundry ventilation is making gains daily, and workmen are no longer compelled to carry on their operations in choking fumes and smoke-filled rooms.

74. The unit heater lends itself admirably to the mainte nance of a comfortable, working temperature in foundry build-

ings—a condition unheard of a few years ago. How many of the men listening to this paper have suffered physically in rooms at temperatures of from 35 to 45 degrees while making molds with sand slightly above 32 degrees, and have lost from a quarter to one-half their day's work?

CONTINUOUS MOLDING

75. In answer to our inquiry as to how many continuous-pour installations there are in the United States, *The Foundry* estimated the number to be about 400 or one-tenth of the total foundry establishments. We believe that this number has been increased somewhat during the year or more since this answer was given. Any foundry manager who is interested in reducing labor costs, thereby substantially lowering the cost of castings and decreasing his foundry floor space at least 50 per cent, should fully investigate this modern method.

76. The fundamental idea of continuous molding is a combination of principles brought into the mechanical field at least thirty years ago and that have been successfully applied in many industries since that time. We enumerated these at the beginning of this paper—the use of mechanical power to move materials, straight-line progress, waist-high operations and reduction of vertical and horizontal movements to a minimum. We may add, in connection with foundry operations, that by divorcing the molder from everything excepting the production of molds, he is able to increase his output from 200 to 300 per cent.

Difficult to Design

77. Designing a continuous-pour foundry is not a simple operation. Sand handling is extremely difficult, as this is a powerful abrasive agent and will not pour. A system of sand control must be devised to add sufficient bond and moisture to continuous movement of material. This must be returned to the molders many times each day free from iron and dirt and cool enough to allow them to work freely.

78. At first, circular-mold conveyors were devised. When permanent molds are better understood and used, such an arrangement may prove very satisfactory. However, large wheels carrying heavy loads offer many difficulties in connection with the central shaft support. The horizontal chain or belt conveyor was introduced and we believe that this is the form that will continue.

79. Molders are arranged along this belt according to many systems both within the belt area and without. The most compact form stations the molding machines within the belt, where cores are supplied the molders by one of several systems. The movement of the mechanism is accomplished chiefly by electric power.

80. Molds may be placed on rolling carts connected with a continuous chain or upon flat trays of metal that slide over lubricated rails. No system can be devised that will prevent sand from spilling into and between the mechanism itself. Molten iron will occasionally run from an imperfectly prepared mold.

81. A well-planned ventilation system must be connected with this to carry off the gases from the castings and the steam that is always generated in the molds themselves. We feel that most mechanical difficulties connected with belt machinery of this character have been overcome. We must now consider the iron-distributing problem.

82. Instead of the operation of the cupola for an hour or hour and one-half in the afternoon, we must be prepared to melt and pour iron from seven in the morning until late in the afternoon. Two or more cupolas must be provided so that at least one may be repaired. Pouring iron at one end of a belt is a much more simple process than carrying it by any known system to remote parts of the foundry. The last floors poured have formerly included cold-shut and mis-run castings even with the most expeditious handling of the materials.

83. Molten iron from continuous-pour cupolas must be hot, and is usually drawn into a large ladle holding 1,000 to 2,000 lbs. or more. This acts as a reservoir and thoroughly mixes the metal. It is a very important, yet simple operation. The use of suitable ladles somewhat smaller in size upon a monorail system makes it possible to carry iron to a continuous-pour belt.

84. Three methods of accomplishing the transfer of iron to the molds offer themselves. The first is to provide ladles, holding perhaps 250 lbs. each, that act as shuttles between the mixing ladle and the mold. According to the second arrangement, the iron is poured into ladles weighing several hundred pounds that serve smaller ladles handled by a group of men before the molds. A third method looks very simple but we have not tried this. This consists in pouring from the cupola ladle directly to the molds.

85. What is the best method of raising and lowering pouring ladles? We may turn to manual control, to electricity and to air.

86. The author of this article is familiar with the cordage and paper industries, where air hoists are freely used when handling rolls and bales of raw and finished stock. An air cylinder is capable of very quick adjustment and is relatively light. If an electric pouring device can be made so light that its inertia is easily overcome, and it yet is strong enough for the purpose, we see no reason why it should not be used with the monorail system. Certainly we should employ power here and should not ask the iron distributor to lift his metal.

SHAKING OUT AND SORTING

87. Hot castings with cores are delivered at the further end of the belt systems. Here they may be rattled to loosen sand and dislodge at least a portion. By means of long-handled tongs and rods, castings may be sorted into trucks at this point; or they may be passed directly into continuous tumbling mills of large capacity, later to be separated according to size and kind while movement is continued upon the belt or other form of conveyor.

88. Sprues are at once returned mechanically to be used in the cupola. Core sand is carried to the electric separator where nails and iron are eliminated, and is later removed to the yard where it serves as filling or for some better purpose.

FINISHING

89. Castings now are ready for the finishing processes—tumbling, sandblasting, chipping, filing and grinding. During all these operations they should be in transit upon conveyors. The workman in charge of each process should remove the piece from the conveyor, do the necessary work and return it for the next operation.

TUMBLING BARRELS AND MILLS

90. The tumbling barrel is a remnant from past generations. It does excellent work but is usually loaded and unloaded as a man-handling job. In line with every other feature of foundry practice, we favor a continuous tumbling barrel.

91. Close approximations are now available. If the appa-

ratus is so designed that castings are easily loaded into the barrel from above at one end or at the side and are conveyed from the barrel without dropping to the floor, we have made some progress in the cleaning room, the last department to be modernized and the most antique of the foundry business.

Chipping and Grinding

92. Large castings are conveniently chipped upon roller conveyors. This operation may be followed by manually operated, power-driven grinders. Small castings may be brought to grinders sitting before their machines prepared to pick up the castings, perform the necessary operations and pass them back to the conveyor. Some workmen will do better with work traveling from left to right; with others, the reverse is better.

The Shipping Room

93. The shipping room is usually at the railroad end of the foundry and presents, in those foundries with which we are acquainted, a fair appearance and economical methods of treatment of bulk and package freight and express incoming and outgoing.

Some Cost Comparisons

94. With few exceptions, we have avoided mentioning costs, as these differ remarkably over the territory represented by this association. We may safely say that iron may be unloaded by a crane and magnet at about one-tenth the cost of hand work.

95. Quoting from one article:[1] "For picking up and transporting small and light objects short distances, nothing is so convenient as human hands; and for moving large and weighty materials, no handling contrivance is superior to a crane." "When light objects are to be moved, figures now show that this is done by hand trucks cheaper than by crane."

96. The perfectly equipped foundry does not exist. We have visited many and have been graciously received. In all instances, at least one feature required more study and further adjustment, or the installation of still another machine. Therein lies the hope for the manager who has just made a start. He is simply a little farther behind the procession than his competitor; both are facing the same way toward an ideal.

[1] Engineering Magazine, Nov., 1915, p. 243.

Neatness and Cleanliness as an Aid to Foundry Operations

By Ed. Trapken, Sandusky, Ohio

Abstract

Progressive foundrymen are realizing more and more that a neat, clean plant is an asset of real value. An orderly foundry, as this paper states, is directly reflected in less delays, less unnecessary labor and general employe efficiency. Indirectly, orderliness and cleanliness minimize accidents and lost time through illness of workers. Also, the author points out, the psychological effect of clean, attractive surroundings is important, as employes whose morale is excellent are more content with their jobs, more active in mind and body and more efficient in their work. There is no necessity for a dirty, disorderly foundry. This paper lists, on the contrary, several reasons why a clean, orderly foundry holds customers.

1. That a foundry without dirt and litter is almost an impossibility is a popular fallacy. For many years the word "foundry" has been associated both in the popular mind and in the minds of the trade with dirt, smoke, heat, confusion and more or less aimless bustle.

2. It is not strange that this notion has persisted for many years, because many foundries throughout the country present a spectacle of confusion and disorder.

What a Foundry Should Avoid

3. Miscellaneous piles of dirty scrap; sundry coke heaps; dilapidated flasks; old riddles; shovels with broken handles; flask weights strewn around; burned-up bottom boards and jackets; crooked, bumpy, metal-littered gangways; no apparent dividing line between molding floors; splashes of frozen metal scattered everywhere; old boxes; heaped-up, forgotten patterns; gaggers under one's feet at every step; blotches of clay wash; heaps of sand and burned cores; a broken window here and there, patched up with an old bag, bottomboard or the nearest article on hand, testifying to futile attempts to keep snow and icy blasts

out—such are the details of the all-too-common picture. Picture at the same time, a laborer shoveling coke or coal into stoves in an effort to keep the plant warm.

4. Environment has a paramount influence upon all life. We are susceptible to conditions affecting our daily toil and business. If our surroundings—in addition to possessing sufficient roominess—are free from petty physical annoyances, and if opportunity is given full swing for doing the job we have on hand, it follows that the job is done in better time and is done in better shape.

5. If, on the other hand, things are all mussed up; if essential facilities are either absent or are very crude; if daylight is poor, or—when surroundings should be illuminated—there is poor illumination, work is neither satisfactory in operation or completeness, nor is the conscientious worker in any degree pleased with his work.

6. Good environment is the master influence. It is the inspiration. It is the first thing indispensable. It is the supreme essential.

How Environment Affects Workers

7. Men love pleasant surroundings in their homes. They would rather have beauty and neatness than squalor, and they would rather have flowers and shrubbery than debris and dirt.

8. They may spend a leisure hour pushing the lawn-mower —not necessary for physical exercise should they be earning their bread by the sweat of their brow—but this menial task they perform because of an inherent love for neatness and order. It is the aesthetic pleasure that comes of contact with nature. This urge they carry with them to the bench and the quality of the products they manufacture or manipulate is enhanced.

9. It may be that the city in which they live possesses unusual physical attractions. This goes far to insure contentment. Public parks and playgrounds; an attractive water-front; public buildings, libraries, schools and churches—all aid the ideals of community life.

10. The homes of the well-to-do, their gardens, lawns and driveways—with all of these the worker comes in daily contact. They heighten his ambitions, for he carries the scent of them and the influence of them to the workshop and the bench. Fortunate is he should the place in which he works be roomy, airy, pleas-

antly located and beautified as much as physical opportunity may afford.

Cleanliness Influences Production

11. The average foundry has too long been regarded as a mere workshop with but one object—production of the thing wanted. Too little attention has been given to those things that aid materially in making a worker one "who needeth not to be ashamed."

12. Happily, it has become an axiom that one who puts himself—plus his craftmanship—into his doing, knows that when

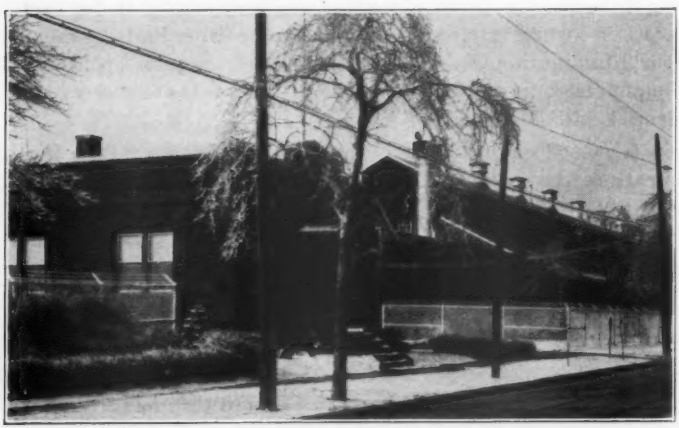

FIG. 1—EXTERIOR VIEW OF THE G. & C. FOUNDRY CO., SANDUSKY, OHIO. CARE IS TAKEN TO GIVE THE GROUNDS AN ATTRACTIVE, BUSINESSLIKE APPEARANCE. TREES AND SHRUBS ARE PLANTED ABOUT THE PREMISES, AND FLOWERS IN SEASON. THE FRONT LAWN IS TERRACED, A NEAT FENCE SURROUNDING THE GROUNDS

the thing he has essayed is finished it stands finished. And this is the product of good environment.

13. Any foundry owes its success to just one thing: Its ability to produce on schedule time large quantities of clean, sound, machinable castings at reasonable prices—reasonable in the light of modern competitive standards. Any policy upon the part of the management that will tend toward such successful production is worth-while, and we submit that cleanliness is one of those policies that pay dividends.

14. Cleanliness and beauty go hand in hand. In fact, clean-

liness is a species of beauty and has about the same effect upon the human mind. In a foundry, above all other places, does the old adage—"He who works in a mess has his mind in a muddle" —apply. It follows that no workman, no matter how skilled, can consistently turn out work of high quality if he is forced to produce in a slovenly and dirty environment.

A Clean Foundry Lowers Its Costs

15. Cleanliness and order are also twins, and the clean factory is usually in orderly array. There is a place for every-

FIG. 2—A NOON-HOUR VIEW OF THE FOUNDRY, SHOWING ORDERLY ARRANGEMENT OF MOLDING FLOORS, BOARDS AND GANGWAYS. NO MISCELLANEOUS EQUIPMENT IS LEFT ABOUT FOR WORKERS TO TRIP OVER AND INJURE THEMSELVES. A WELL-LIGHTED, WELL-VENTILATED AND CLEAN FOUNDRY, CONDUCIVE TO BEST WORK ON THE PART OF MOLDERS AND LABORERS.

thing and everything is in its place, resulting inevitably in time-saving short-cuts that always find expression in lowered costs.

16. Cleanliness and soundness are usually found together in animals, in vegetables, in machinery and in buildings. Clean chimneys usually do not catch fire. Clean windows are usually not broken out to admit more light.

17. Clean electric systems result in fewer short circuits. Thus it follows that cleanliness results in a direct and tangible saving of equipment, materials and scrap.

FIG. 3—GIRL WORKERS ARE EMPLOYED IN THE CORE ROOM, WHERE FLOORS AND SURROUNDINGS ARE KEPT AS CLEAN AS POSSIBLE. RUBBER MATS PLACED ABOUT THE CORE BENCHES ARE LESS TIRING TO THE FEET THAN CONCRETE FLOORS. CORES ARE STACKED IN WOODEN TRAYS ON STEEL PIPE-RACKS WHICH ARE ADJUSTABLE IN HEIGHT.

FIG. 4—THE G. & C. FOUNDRY READY FOR MOLDING TO BEGIN, SHOWING SAND HEAPS ARRANGED NEATLY AND UNIFORMLY. A CENTER GANGWAY OF CONCRETE FACILITATES HANDLING MOLDS AND SUPPLYING MATERIALS WITHOUT INTERFERING WITH OPERATIONS.

The Relation to Safety Work

18. Cleanliness in foundries bears a pronounced relationship to the prevention of accidents and the maintenance of healthful, sanitary condition of workers. Accidents, and days lost through them, govern industrial insurance rates to such an extent that in some cases a reduction of 15 to 20 mills can be secured by plants that are in a position to keep "Safety First" methods uppermost in the mind of employes.

FIG. 5—IN THE SHIPPING ROOM ALL SMALL PARTS TURNED OUT ARE STORED IN BINS OR BARRELS, FOR CONVENIENCE IN FILLING ORDERS. WHERE PRACTICABLE, LARGER ARTICLES ARE STACKED NEATLY. THE ROOM IS WELL LIGHTED ALSO, WHICH AIDS MATERIALLY IN MAKING SHIPMENTS PROMPTLY.

19. Industrial insurance has no small share in the operating cost of a plant. Days lost through accidents and preventable illness by reducing production, and the paying out of industrial compensation besides, must increase cost figures and thereby reduce profits.

20. It is difficult enough to attempt prevention of accidents in a plant which, through neat and sanitary surroundings, sets

up a pronounced example to all employes every minute of their working days. How much less will the worker be found to pay attention to Safety First and Good Health campaigns, when the incentive of good, practical example on the part of his employers is sorely lacking?

An Attractive Plant Is an Asset

21. A clean, attractive, orderly foundry holds customers in several different ways, as follows:

The plant itself is a talking point noticed and discussed by traveling men, customers' representatives and fellow foundrymen.

A clean, beautiful foundry attracts competent and efficient employes, and what is more, holds them there. And there is no greater asset to any manufacturing plant than loyal, efficient, contented employes. Such employes satisfy customers.

A clean, orderly foundry must of necessity be so laid out that it minimizes unnecessary labor and time-consuming delays, all of which, as indicated above, are directly reflected in low costs. And that means ability to meet competitive prices.

A clean, well-kept foundry depreciates very slowly and replacement costs are thereby lowered, releasing funds for research and quality improvement.

Points Not to Be Neglected

22. Do not hesitate to clean your windows; sweep your floors; collect and segregate your dirt; level up and weed your yards; paint your machinery, window frames, cupola, molding machines and other perishable equipment. Also, brighten up the electric lights, put your wires in conduits, plant some flowers around and keep the lawns clean.

23. To have one's factory in good physical condition is to maintain property values at their maximum and to impress visiting buyers with the unspoken conviction that "here is a place where orders will be taken care of." The advertising value of such conditions is inestimable.

24. The safety element falls in logically with the general scheme of things. Men cannot help taking a special care of the machinery that is their co-worker. It comes naturally to them when surroundings are satisfactory.

Overcoming Alloy Ingot Troubles in the Brass Foundry

By Wm. E. Paulson,* M. E., Brooklyn, N. Y.

Abstract

Use of alloy ingot was resorted to in order to meet increasing price competition. A most carefully selected ingot gave castings which presented machining troubles. Specifications which were prepared to exclude all impurities known to be detrimental did not eliminate the difficulty. Finally, ingot metal specially prepared from clean copper scrap and solder metal was secured and production troubles were overcome.

1. These remarks are intended as a purely non-technical discussion of the difficulties experienced by one foundry in producing nonferrous castings using alloy ingots. The writer feels that this subject is a timely one, inasmuch as other foundries undoubtedly have had similar experiences with the use of alloy ingots. It is through the aggregate of experience and knowledge, of course, that we mutually better our methods and products.

2. Our foundry, to begin with, has been producing high-grade products for over forty years. Up until a few years ago, we held to the opinion that it was necessary to use virgin metal in order to procure the results we sought to accomplish.

Why Alloy Ingots Were Considered

3. A short while ago, however, price competition forced us to consider means for reducing our costs, while still continuing to maintain the quality of our product. Thus we turned to the use of alloy ingots, although it must be admitted that we adopted this policy with misgiving, having in mind the homely saying that "You can't make a silk purse out of a sow's ear."

4. Ingots were procured from a well-established concern of unquestionable reputation. It is only fair to state here that

* President, Thomas Paulson & Son, Inc.

none of the writer's comments are intended to reflect in any way upon this ingot producer's skill or integrity.

First Observations

5. The first castings which we made from the ingots were, of course, examined with great interest. For one thing, in skimming the molten metal it was observed that more than the usual amount of dross was removed. Also, the castings, when taken from the mold and cleaned by the sand blast, exhibited a decidedly different color than was the case with castings poured from virgin metal mixtures.

6. In composition, the mixture which we are now considering consisted of copper 77, tin 8, and lead 15. An alloy consisting of copper 80, tin 10 and lead 10 behaved in the same manner.

7. After being reassured by the ingot producer that the conditions observed were not detrimental to the metal, the castings were shipped. As production continued, it was further observed that the surface discoloration was not consistent. That is to say, different heats exhibited marked differences in color, despite the fact that chemical analyses indicated close adherence to specifications.

Causes of Failures

8. After a number of lots of ingot metal castings had found their way into the machining departments of customers, it was not long before complaints began to come in with distressing frequency. The experiences reported by several shops were substantially identical.

9. No two lots of castings machined the same. All users were agreed that the machining time was increased. In too numerous instances, reports came in to the effect that many castings were unmachinable. Many castings, of course, were returned for credit, so that the anticipated foundry economies were wiped out and, indeed, production costs increased.

All Impurities Excluded

10. At this stage, metal specifications were prepared excluding all impurities known to be detrimental. These impurities included iron, antimony, nickel and phosphorus.

11. We were assured by the ingot producers that, with rigid adherence to these specifications, the difficulties we had

been encountering would not recur. Feeling confident that this contention was correct, we proceeded with new ingot metal.

12. Our hopes were somewhat shaken to find, first, that the surface color was little improved. Also, customers using the castings reported little improvement in machinability. We watched many machining operations at this stage of the work, and we were convinced that the claims made as to working difficulties were well founded.

13. It was then decided to call in a new source of ingot supply, and with this producer our previous troubles were discussed at great length. It is well known that those of us who are engaged in foundry work seldom succumb to discouragement, so with new ingot we again proceeded, with renewed hope. However, these hopes were quickly dashed, for the same troubles immediately asserted themselves.

Trouble Is Traced Down

14. It is well to mention here that machining difficulties had manifested themselves in cutting tools being quickly dulled. Examination of the machined surfaces showed small spots that appeared very hard.

15. It had now become only too apparent that this condition had to be remedied immediately if customers were to be retained. Several, indeed, had already placed their business elsewhere.

16. At this time, we are using ingots in producing castings in the two alloys discussed in this paper, and these castings are apparently the equal of virgin metal products. This result is being accomplished by the use of specially prepared metal.

17. No turnings enter into the composition, nor is any red-metal alloy scrap permitted. The mixture is prepared from clean copper scrap and solder metal, with necessary additions of tin and lead, and the whole bath of approximately 25,000 pounds is carefully refined in a reverberatory furnace.

18. The conclusion that has been forced upon the writer confirms his belief, held prior to the use of the alloy ingot, that virgin metals or their equivalent (the latter obtained by preparing ingot as described above) are absolutely essential for production of best quality castings.

(Discussion of the preceding paper is combined with that of the following paper, and will be found on page 201.)

Application of Brass Ingot Metal in Industry

By Wm. Romanoff,* and C. O. Thieme,** Chicago

Abstract

The development of the use of ingot metal from secondary metals has been an economic necessity. Improper foundry practice has been the main cause of most of the troubles arising from the use of both virgin and secondary metals. The ingot metal is made by the refining of sorted secondary metals, which removes the impurities, after which the metal is built up to specification and poured into ingots. The same physical properties may be obtained from properly refined ingot metal as from virgin metal, while considerable saving can be secured through the use of the ingot metal. "Burnt" metal is really a misnomer, for brass is not burnt the same as steel. Some of the constituents may be oxidized or volatilized, due to wrong furnace atmospheres or excessive pouring temperatures. An example is shown where standard ingot metal was remelted ten times without change in the physical properties. Trouble can occur in a foundry regardless of what metal is being used.

1. The ingot brass industry has made rapid strides during the past ten years in the development of processes and improvement of the quality and uniformity of the product. This, to a large degree, has overcome the "conscientious objection" to the use of its products.

2. The smelter and refiner began to realize that, to survive, they must consistently make a product which would satisfactorily compete with virgin metals. Years ago ingot manufacturers did not enjoy a healthy reputation, but we believe this was due to metallurgical ignorance of those in the ingot business rather than to any malicious attempt to misrepresent their product or to make ingot not uniform or properly refined.

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*Technical Superintendent, H. Kramer & Co.
**Metallurgist, H. Kramer & Co.

3. Through all this it was realized also that in order to make a good product technical control must be established. Imaginative secretiveness is disappearing rapidly among the brass ingot manufacturers and now, after years of diligent effort and research, tremendous improvement is noted.

APPLICATION

4. It is a known fact that the most vital factor in the manufacture of good castings is that of foundry practice. Improper gating of castings can cause a shrinkage condition, dirty castings, misruns, etc. The wrong pouring temperature will cause the castings either to misrun or to be porous throughout as well as rough on the surface. Shifted castings are usually due to defective pattern equipment. Poor sand conditions will create surface porousness or roughness and other ailments.

5. So much has already been written on furnaces and melting atmospheres—and, so that we may continue a treatise on the ill or good effects of foundry practice indefinitely—we will eliminate these factors entirely from our discussion.

6. After foundry practice, the question of metal arises, and under this heading the application of brass ingot metal. By ingot we mean a cake or block of alloyed brass or bronze that has been obtained from the refinement of secondary metals as a base. This refinement, in general, is as follows:

7. Secondary metals are sorted into various classifications and then melted in large quantities, usually in the open-hearth type of furnace, although other types of furnaces find application with some types of alloys. After melting, air is introduced, which either eliminates the easily oxidizable impurities—such as silicon, manganese, aluminum, phosphorus, iron, etc.—or reduces them to percentages not objectionable nor detrimental.

8. After these impurities are slagged off the top of the bath, the molten metal is then poled with green saplings to reduce the oxides of the main constituents formed by the introduction of air. During this entire process, chemical analyses are made and test plugs are examined. The metal is then built up to specification and poured into ingot.

9. We have found from experience, observation and test that any brass and bronze castings which have been or are being made from virgin metals can be made from ingot without detrimental lessening of the physical properties. Of course, certain

castings call for chemical specifications which are not within the range of ingot manufacture, but most of these chemical specifications are more traditional than essential.

10. In the past, too much stress has been placed upon chemical characteristics of metal when it really was subservient to foundry practice in obtaining the desired physical properties. Time and time again, we have obtained a variation of as high as 10,000 lbs. per square inch in tensile strength from the same pot of metal, merely by varying the pouring temperature; and there certainly was no change in the chemical analysis of the various test bars poured.

11. In line with this, a special committee of the American Society for Testing Materials, working in conjunction with the Non-Ferrous Ingot Metal Institute, has found that there are about six hundred different specifications for brass and bronze ingots, which no doubt can be reduced to about thirty or less. Supposedly, at various times castings have been analyzed and these analyses set up as specification without rhyme or reason.

INGOT VS. VIRGIN METAL

12. Without question, copper is the most delicate of the metals used in the manufacture of brass and bronze, due to its tendency to absorb gases readily—both oxidizing and reducing gases. Foundrymen know that as the copper content of castings increases, the difficulty with non-metallic impurities also increases.

13. They seldom have trouble with low-copper-content castings in so far as non-metallic impurities are concerned. Most of the grief in the much-abused manganese bronzes is due to improper gating and pouring temperatures and not to non-metallic impurities.

14. In melting virgin metals, the copper is melted first and the tin, lead and zinc added later. The copper may be thoroughly oxidized before the latter is added. This is partially avoided by the use of ingots as the copper, tin, lead and zinc are thoroughly alloyed or mixed before placing the charge into the furnace. As the latter are natural deoxidizers for copper, there is thus greater opportunity for obtaining sound castings when ingots are used.

15. Again, in the use of virgin metal, the copper, tin, lead and zinc must be weighed separately. This may work havoc if

chemical analysis, uniformity of product and maximum physical properties are desired; if a mistake is made in weighing, the chemical analysis is "thrown off," and often the change in properties of the alloy seriously affect machine-shop operation. This is not true when ingots are used, for if a mistake is made in weighing there is simply more or less metal without affecting the analysis in the least.

16. We do not wish to convey the impression that virgin metal cannot be used successfully. We merely wish to point out the fact that ingot is more "fool proof."

17. In Table 1 it will be noted that we obtained practically the same physical properties from test bars poured from ingot and from virgin metal where they were both melted and poured under the same conditions. Standard 85-5-5-5 was used.

Table 1

PHYSICAL PROPERTIES OF VIRGIN AND INGOT METAL MELTED AND POURED UNDER SAME CONDITIONS

	T. S., lbs. per sq. in.	Elong., Per Cent.	Brinell.	P. T., degs. Fahr.
Virgin alloy	33,300	23.0	57.5	2100
Ingot alloy*	32,250	21.0	57.5	2075

*Average of 28 heats.

18. In passing, we must not overlook the fact that, granting all things being equal in so far as physical properties and good castings are concerned, considerable saving can be made by using ingot instead of virgin metals of the same composition. In these highly competitive days this may determine the difference between a profit and a loss for some foundries.

HAS "LIFE" BEEN "BURNED" OUT OF INGOT METAL?

19. We often are confronted with the argument that the secondary metal from which ingot is made has been remelted so many times that the "life" has been "burnt" out. "Burnt" metal is really a misnomer. What is really meant is oxidized metal.

20. We may oxidize or volatilize some of the constituents, particularly zinc and lead, but we do not burn brass like we do steel. In the latter it happens in the solid state when, during a heat-treating operation, the temperature is brought up to such a point that gases get into the steel and separate the crystals.

When such a condition is found in brass, it is more often due to furnace atmospheres and excessive pouring temperatures.

21. The results given in Table 2 prove that, for practical consideration, the number of times metal is remelted does not affect the physical properties if carried out under the proper conditions and if the chemical composition is maintained.

22. Standard 80-10-10 and 85-5-5-5 ingot were remelted ten times, each time some test bars were poured and the balance of the metal was poured into ingots and remelted. Zinc, tin and lead were replaced as found necessary. It will be noted that the physical properties are practically the same.

Table 2

EFFECT OF REMELTING ON PHYSICAL PROPERTIES OF INGOT METALS

	80-10-10			85-5-5-5	
	T. S., lbs. per sq. in.	Elongation, Per Cent.		T. S., lbs. per sq. in.	Elongation, Per Cent.
1	29,600	9.0	1	31,050	23.0
2	29,850	9.0	2	31,500	21.0
3	29,950	10.0	3	32,000	20.0
4	28,500	10.0	4	33,000	19.0
5	29,200	11.0	5	32,200	22.0
6	29,950	9.0	6	31,700	20.0
7	30,600	10.0	7	32,000	20.5
8	29,950	10.0	8	32,600	19.0
9	30,500	10.0	9	33,400	21.0
10	31,500	9.0	10	32,100	22.0
Usual Specification	28,000	8.0			

CONCLUSION

23. We do not feel that in this short discussion we have covered all the details regarding the application of ingot to industry. We believe, however, that we have shown that just as good results can be obtained from ingot as from virgin metal, and that it is more "fool proof" in its use, in addition to effecting a saving in money.

24. We have also proven that metal can be remelted any number of times without deleterious results. This fact should eliminate the old "bugaboo" that ingots are inferior because they are made from secondary metal which may have been remelted many times.

25. The pendulum is swinging the opposite way. Today,

foundrymen who still use virgin metal either are remelting it into ingot before using, or are purchasing an ingot made from virgin metal.

26. In closing, we might again repeat that trouble can occur in a foundry regardless of what metal is being used, but that, with proper foundry practice, there will be less trouble with ingot.

DISCUSSION

ORAL DISCUSSION

I. E. WAECHTER:* Referring to Mr. Paulson's paper, while our attention is called to various things that are very timely, I noticed that he had the same trouble so far as discoloration and machinability and everything else, using virgin metals, as with remelt ingots. I do not see how the conclusion can be drawn from these remarks that virgin metal is superior to ingot in eliminating machining troubles or eliminating discoloration troubles.

When we have used virgin metals, our loss—the furnace loss or all kinds of unexplained losses—were smaller than if we used remelted gates but not necessarily when we used ingots, although we have had excessive loss using certain kinds of ingots.

WM. E. PAULSON: The discoloration mentioned did not occur when we used virgin metal. We only had discoloration—unexplained discoloration—when we were using alloy ingot.

Further, in using ingot made from this high-grade copper scrap and solder metal, and building it up to the specification, we are getting color equal to that obtained with virgin metal.

I. E. WAECHTER: Paragraph 12 reads: "Our hopes were somewhat shaken to find, first, that the surface color was little improved. Also, customers using the castings reported little improvement in machinability. We watched many machining operations at this stage of the work, and we were convinced that the claims made as to working difficulties were well founded."

In paragraph 11 it says: "We were assured by the ingot producers that, with rigid adherence to these specifications, the difficulties we had been encountering would not recur. Feeling confident that this contention was correct, we proceeded with our orders using new ingot metal."

Where Mr. Paulson says, "the surface color was little improved," I understand this to mean that the color was not improved very much. Also, "Customers using the castings reported little improvement in machinability," I take to mean that improvement in machinability was not very noticeable.

W. ROMANOFF: I wonder whether Mr. Paulson jumped at con-

*National Bronze & Aluminum Foundry Co., Cleveland.

clusions, or whether he attempted to analyze the particular cause of machining difficulties. It is a proven fact that in nonferrous work the majority of machining difficulties are caused by surface inclusions such as free iron, sands, slag, etc. A tool striking these inclusions will be dulled, and from then on all of the castings will apparently be difficult to machine, even though they are not.

Whether these inclusions are caused by the particular metal used is problematical. Experience has taught that most sand and slag inclusions are caused either by poor skimming, improper sand or dirty molding or by a combination of these factors. The iron inclusions may come from an iron skimming or stirring rod being washed into the metal, or from non-magnetic borings.

It is a known fact that psychology plays an important part in the machining of castings. When the average machine operator knows that other metal has gone into the castings, he usually will find a difference in the machining properties, whether there is a difference or not. In other words, he will be looking for trouble, and we usually find what we are looking for, even though we find it in our imagination.

Also, how about tool steels and their heat treatment? Have not these ever been known to be defective?

Mr. Paulson mentions that you cannot "make a silk purse out of a sow's ear." Evidently he refers to the fact that ingots are made from secondary metals. However, secondary metals seldom contain over three per cent of impurities, while the so-called virgin copper is seldom made of an ore containing less than 50 per cent of impurities. In fact, a great deal of electrolytic copper is now being made from secondary metals instead of from native ore.

W. E. PAULSON: I believe that we did make investigations which, at least in part, bear out our contention. I said a while ago that we want to use ingot to begin with.

In regard to the matter of the iron skimmer, we do not use an iron skimmer. We use an alloy steel skimmer for that very reason, because we have had the trouble mentioned.

As to the psychology that enters into the machining of these castings, I do not believe that had anything to do with the difficulties, because the castings were machined in another shop, not in our own shop. Thus, the machinist probably did not know just when the castings were made out of alloy ingots and when they were made out of virgin metal.

If we had three per cent of impurities in the castings, we would not be here discussing it, because we could easily find them. It is the fact that we have such an infinitesimal amount of impurity that gives us the mysterious difficulty under which we have been laboring.

The castings produced from alloy ingot—made from selected copper scrap and solder metal—and which have all the appearance of virgin metal products, show no inclusions that are visible on the surface, and they machine about the same as castings made of these mixtures from virgin metal. However, the general run of ingot that we have just bought from reputable manufacturers has been giving us this trouble,

not once but many times. Consequently, I hope the alloy-ingot makers will be able to show us what the trouble is and improve their product if that is the difficulty.

If we had the same difficulty with virgin metal that we have been having with ingot, we would have to take considerable blame on ourselves; but there seems to be some very small impurity that gets into these alloy ingots, causing us the trouble that we complain of in these leaded mixtures. We do not have it with the 85-5-5-5 and allied alloys.

MEMBER: Some of us who have been using ingots for a great many years remember that some manufacturers in the early days gave us a very, very inferior product in comparison with what we have today. However, you still can buy very inferior ingots, which will give the results of which Mr. Paulson speaks. If one looks for a question of price on an ingot, one can get the same kind of material the author has mentioned.

We do not favor a straight use of ingot in certain lines of work. We use a great many of them in our foundry, but also use considerable virgin material. We find that it pays a little better to do that. Our loss in leakers is considerably less.

In the matter of running into hard metal and injuring tools, a thousand and one things can cause that aside from impurities in the metal. We have a very strenuous argument between the finishing department and the foundry right now in regard to sand blasting. The machine department contends that sand-blast castings wear out tools much more quickly than washed castings. I cannot accept this statement as a fact.

I believe that if a man goes to work today with the ingots that are being produced by reputable manufacturers, and if he pays the price, he will get very satisfactory results.

G. H. CLAMER:* There is a great deal of justification in what Mr. Paulson has told us. It is entirely a question of minute impurities—perhaps not only one, but a combination of three or four impurities, all present in small amounts.

A man may get a very brilliant idea. He thinks it is patentable, and he goes to the patent office with an application describing it. Yet he is apt to find that someone has preceded him by thirty or forty years with the same idea. I do not wish to detract at all from Mr. Paulson's rediscovery of the way to make high-class ingot. The only trouble with his method is the price of the product.

Soon after leaving college, I went with the concern with which I am still associated. We then were manufacturing 80-10-10 alloy—not exactly 80-10-10, but 77-11.5-11.5. Up to that time we had used virgin metals. Market conditions were such, up to then, that the use of virgin metals was permitted by the selling price. Shortly thereafter, competition sprang up and it became necessary to cut costs. The first thought that came to me to cut the cost was to use heavy copper and solder metal.

*Ajax Metal Co., Philadelphia.

Heavy copper then sold at a differential, as it does now, of about 1½ cents a pound under the price of ingot copper, and the solder metal sold at 1½ cents to 2 cents below the price of the constituent lead and tin. So we made our alloy in that way thereafter.

We did not use reverberatory refining, however. As a matter of fact, it is questionable if that is necessary, providing the atmosphere in the furnace is maintained and proper covering, etc., is used to prevent the metal from becoming deteriorated during the melting operation.

The alloy so made has practically no impurity in it other than antimony. Iron and particularly phosphorus are not present. When ingot metal is made from red-brass turnings, etc., these elements are present, but it is possible, of course, to eliminate them entirely, and also the aluminum. These are oxidizable constituents. There still may be a combination of these impurities in minute proportions that will affect the skin color and machinability.

The problem of the ingot manufacturer is to produce quality ingot at a price sufficiently below mixture cost on a virgin-metal price basis to be attractive to the buyer. Mr. Paulson evidently is in a position to pay more for ingot than the usual ingot consumer. Being in such a position, he can use an ingot made in the manner he describes.

A. W. LORENZ:* We, too, are interested in the use of ingots, and every once in a while we decide that we will try some ingots again. On our last attempt we ran into some of the same problems Mr. Paulson encountered. We got that peculiar color which does not occur with virgin metal, and of course our machinists complained about it right away and said it was too hard to machine.

We thought also of psychology and shook out the castings in a different manner so as to get a little red color on them. Then we took them up to the machine shop; but they were still hard to machine. Thereupon, we adopted the psychology of making them go ahead with it, and after a while they got used to it.

Mr. Paulson makes the remark that, in using their newly compounded ingot metal, they use no borings. We are forced by necessity to use about 50 per cent of borings in our mixture—borings which are returned from our own machine shop, from castings coming from our own foundry. We know what their composition is.

When we use that amount of borings, we do not get good castings of ingot metals, although we can get them from virgin metals. If we cut down borings to about 35 per cent, then we can get good castings from ingot metals.

WM. EMBER:† We have been experimenting with ingot metal for the past two years, and we very much want to use ingot metal. However, in using ingot supplied by four of what we think are leading manufacturers, we ran into the same troubles encountered by Mr. Paulson, and more besides.

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*Bucyrus-Erie Co., South Milwaukee, Wis.
†Jefferson Brass Foundry, Brooklyn, N. Y.

To begin with, we put our proposition up to the ingot makers and told them emphatically that we were not talking price—we were talking about metal and that, after the metal was satisfactory, we would discuss price.

Our success with ingot was very poor. Our customers did not know that we were changing the metal to ingot, for we took precautions to keep the knowledge from them. When we did send them castings from the ingot metal, however, there were great complaints.

We did some further experimenting. We were unable to stop the trouble, but to use up the metal we had on hand we finally found, through experimentation, that if we used approximately 40 per cent virgin metal and approximately 60 per cent ingot, the trouble practically disappeared. This would seem to bear out Mr. Paulson's statement that there are some minute impurities in the ingot metal which, when cut down by mixing with the virgin metal, are so diluted that the trouble is greatly, if not entirely, overcome.

LOUIS SANDLER:* We use a considerable quantity of ingot metal today. Dating back 14 years, we used virgin metal. From that point we swung to the other extreme, using considerable scrap. However, we ran into tremendous difficulties, due to finding impurities such as aluminum bronze in our scrap, which we figured was very expensive. Thus we turned to ingot metals.

As a foundry superintendent, I ran into the troubles of the machine shop complaining about hard metals. This was the case all the time, because the operators usually got a reduction in rate when they complained of hard metal.

As a factory manager, I find that has disappeared entirely. I refused to recognize anything like hard metal. The only trouble which can be found when an operator is having trouble with ingot metal is slag inclusions or sand holes, which naturally will knock the edge off a tool.

We use considerable amounts of 80-10-10, S. A. E. 66, gun metal, high-lead ingot and almost every alloy made. There are impurities in ingot. When we buy ingot metal we specify absolutely the amount of iron, nickel, phosphorus, antimony and other impurities that may be found and which the ingot manufacturers cannot remove.

I believe we get a better product from ingot metal than from new metal. In starting with new metal, some people might say that scrap copper wire is virgin metal, but today we have a proposition with scrap copper wire that did not exist years ago. With the present copper-clad wire that cannot be told from pure copper wire, the foundryman will find that he is in considerable difficulty, especially when he has not the facilities to take it up to the laboratory, analyze it and find out what his troubles are. There is no doubt that free iron will give a foundryman great trouble.

One theory I have always worked on is this: If the foundryman starts with a diseased metal, he will finish up with the same proposition. It is up to the foundryman to see that his ingot metal is first

*Johnson Bronze Co., New Castle, Pa.

class; if he starts with good ingot metal and his practice is good, he should finish up with a good product.

There is no reason why ingot metal should be different from virgin metal. As a matter of fact, it is harder to alloy virgin than ingot metals.

In melting metals, there is a paradox in that, as the metal gets hotter, sometimes it looks colder to the furnace tender. That is, when he melts his copper and gets his alloy melting in his furnace, as he heats the metal up there is a possibility of oxidizing the lower-melting-point metals. As this occurs, a higher-melting-point metal is being approached, and the metal becomes slushy and looks as though it is becoming colder. The furnace tender, in giving it more heat, actually destroys the alloy.

We get just as good tensile strength from ingot. We make any kind of castings, with any tensile or chemical combination, and we have no trouble. Once in a while, of course, we get a bad car of ingots. The ingot manufacturers are just as liable to turn out a bad car of ingots as we are liable to turn out a bad heat from our furnaces, but it is up to the foundryman to spot that car before he starts using it.

Taken all in all, we have gone absolutely to 100 per cent ingot, with the exception of a case where a customer comes in and orders a special alloy which must be made from virgin metal, especially as the amounts do not warrant ordering a carload of ingots.

WM. E. PAULSON: Mr. Sandler said that it is up to us to determine whether or not we are getting first-grade material from the ingot maker. It may be a reasonable precaution for us to attempt to determine whether it is or not, but when we are dealing with a reputable house, which we all try to do, we feel that it is up to the ingot maker to deliver us material to specifications.

When we deliver castings to a customer, he does not feel that it is up to him to determine whether it is up to specification or not; and if it is not, of course he immediately throws it back.

The ingot men do everything possible to give us a good ingot, they feel responsible for it, and they do not feel it is up to the foundryman to check up every ingot of metal he purchases.

MEMBER: The point of buying on specification is a very good one. If anyone were to buy any other product, he would buy on specification. Why not, then, buy their various ingots on the same plan? That will eliminate quite a few impurities that cause these hard castings to which reference has been made.

We have obtained on an 85-5-5-5 mixture much higher physical results by using bought ingots than Mr. Romanoff reports with virgin metal. Therefore, due to their being cheaper and their melting loss being somewhat less than other metals, I believe there is an advantage to the average foundryman in bought ingots.

G. H. CLAMER: Mr. Paulson's chief requirement is one of skin color. Skin color is influenced very largely by the degree of impurity—the amount and kind of impurities present may affect the color greatly.

The question of machinability, of course, is a debatable one; but

that one feature, namely, the skin color—which is apparently of prime importance—concerns Mr. Paulson because he is in the jobbing business and wants to sell castings having a bright and pleasing color.

There are other uses where the surface color is of no importance. I believe there is no question about the desirability of using properly refined ingot for the large majority of uses, because of the great saving.

JOHN C. SCHELLIN:* We do not use a great deal of metal, but I wonder if some men who are in the metallurgical field realize that we get different discoloration by the use of different sands—by different foundry practices.

We have purchased ingot to analysis, checked it, rechecked it, double-checked it again. Certain ingot manufacturers will produce an ingot that will give a certain machinability, a certain tensile strength. Metal made by the same analysis but by other ingot manufacturers may give just the reverse in machinability and tensile strength.

H. M. ST. JOHN:** We have been using ingot metal for a great many years. We had trouble at first, and discovered two things: First, we had to be very careful in our specifications for the purchase of ingot metal; second, we had to control our own practice much more carefully when we used ingot metal than when we used virgin metal.

Nevertheless, having established what seemed to us satisfactory specifications, and having established the control, and for the last five or six years using a variety of alloys, we get at least as satisfactory results with ingot metal as we ever did with virgin metal, and certainly at very much less cost.

R. L. BINNEY:† In the paper by Messrs. Romanoff and Thieme, in Table 1 they give some physical properties of the virgin alloy as compared to the ingot metal. Have these been carefully researched? Usually, when a fellowship is established or someone is doing advanced work, they are very particular to specify whether the specimen upon which they are working is from virgin metal or from remelted metal or secondary metal.

In defense of the ingot maker—in whom I have no personal interest—I believe that with a good ingot we can get better physical properties than when we start with pure virgin alloys. It is some years since I have actually worked in the laboratory, but I have pulled some ten thousand bars in my time and analyzed equally as many samples. I find also, in operating my own business, that while we start many heats on a virgin basis, the physicals are somewhat less in such heats.

In talking with other metallurgists and people interested in this subject from a purely academic standpoint and not selling something, that view has been substantiated. Therefore, in this paper where the authors claim that the virgin metal gave them practically the same thing as ingot metal, I do not believe they used good commercial judgment—their virgin results would be less than the alloy results.

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*Akron Brass Mfg. Co., Wooster, Ohio.
**Detroit Lubricator Co., Detroit.
†Binney Castings Co., Toledo, Ohio.

Not only the very simple physicals given here, but also many other properties of alloys which influence their commercial value to the consumer, will be found to have physical properties that are better after one or two meltings—provided good practice is used—than the properties obtained when made from virgin metals.

W. ROMANOFF: If Mr. Binney will read the paper properly, he will notice that the virgin metal he speaks of is virgin alloy, not virgin metal. The metal was melted up into alloy first before the test was run, so that we get a uniform analysis.

W. B. GEORGE:* We have run a number of tests on machinability of brass castings, and we have found cases where we could get hard and soft metals out of the same pot. This may sound queer, but it is so. We melt 270 pounds of metal per crucible.

With an 85-5-5-5 mixture, when a cut is taken on some of these castings, the tool will burn up and the material will be stringy. These castings were poured from the top of the pot, as upon analysis we find that the lead had settled to the bottom.

Every foundryman knows that the metal should be stirred every few molds, but it is not always what we know that counts, but what we do. We have found lead going up to eight per cent on the bottom of the pot and coming down to three at the top.

We add 0.01 per cent phosphorus to our mixtures for a deoxidizer and find that all of this is not burned up and a portion is left combined with the metal. On remelts this keeps building up and our castings become harder. If a straight heat of gates and scrap is used, we find them decidedly harder.

We also find that, when using phosphorus for a deoxidizer, the unburned portion settles out or forms compounds in our heavier castings, giving a different machining quality than the lighter ones. From combined phosphorus the metal will be hard and of a different nature than that from the loss of lead.

WRITTEN DISCUSSION

N. B. PILLING:† In Mr. Paulson's discussion, nickel is included among the elements which he has found to be detrimental in bearing-bronze ingots of the 80-10-10 type, and which he seeks to eliminate through specification. As nickel has found a distinct utility in alloys of this type, its general condemnation as an unwelcome element is apt to be misleading to those not fully informed as to all the circumstances involved.

None of the trouble which Mr. Paulson eliminated by control of his scrap corresponds to the known action of small contents of nickel in the 80-10-10 mixture. The classification of nickel as an "impurity known to be detrimental" should not be accepted without a further statement as to how much nickel the author found to be detrimental, and how its harmful action was displayed.

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*Sloan Valve Co., Chicago.

†International Nickel Co., Bayonne, N. J.

REPLY BY AUTHOR

WM. E. PAULSON: It is noted that Mr. Pilling objects to the classification of nickel as "an impurity known to be detrimental" to alloy ingots containing copper, tin and lead. Since the point is raised in this manner, the author contends that the beneficial effect of uncontrolled nickel is debatable. The writer has already admitted to Mr. Pilling, in private correspondence, that we are not sweepingly condemning this element, but that, on the contrary, we fully agree that it is one of the most useful in the Arts.

It is our belief, however, that it is not a nostrum, and that its effect in small quantities in the presence of many other metallic and non-metallic elements cannot always be determined.

The author found himself in great difficulty with alloy ingots of the classification under discussion, due particularly to the inability to machine castings made from such ingots. The position was taken that, if an element was excluded, any harmful results due to its presence surely would be eliminated. Since the discussion which the author raised had nothing to do with nickel, but rather with a copper, tin and lead alloy in which nickel appeared as an impurity, it does not seem expedient to continue the discussion along this particular line.

There is, in the author's opinion, a difference in the effects produced by the controlled use of nickel as against its uncontrolled use. It is the uncontrolled nickel which we desire to exclude.

Factors Affecting Machinability of Malleable Cast Iron

By H. A. Schwartz,* Cleveland

Abstract

Considerable difference of opinion exists on whether or not high-carbon malleable cast iron is more easily machinable than low-carbon metal. The common points of view of both schools of thought are examined and compared, and the author presents the available evidence for the case of users and producers. In his experimental work to obtain authoritative information, the author excluded tests on abnormal iron, confining his investigation to metal of an analysis at least comparable with the usual commercial irons. In deciding upon experimental methods of determining machinability, it was realized that there is a great difference of opinion as to what constitutes machinability, and that tests to give the same information as obtained under actual operating conditions would be impractical to carry out. The test procedure decided upon was one which measured tool stress at given feeds and cutting speeds. Tests were made under which there were measured (1) the torque and thrust of a drill advancing at constant speed and (2) the feed and torque of a drill advancing under constant pressure. Corroboratory experiments for other machining methods, turning and threading were carried out on a limited scale. The problem for solution was stated to be the determination of whether there is a relation between machinability and tensile strength in malleable iron. Specimens were obtained from 14 malleable plants; data of tests are given and discussed. The author concludes, from the data obtained, that the machinability of malleable iron, as measured by drill testing, is very largely determined—as are its other physical properties—by carbon content, and that the threading tests are of general interest only and cannot be given too much weight. The indications from the turning tests showed that in the outer $\frac{1}{32}$-in. of the castings the results are so erratic as to permit no general conclusions as yet. Observations are recorded showing even well marked exceptions to the expected relations that outer skin is more difficult to machine than the heart.

*Manager of Research, National Malleable & Steel Castings Co.

INTRODUCTION

1. There probably is little doubt that malleable cast iron, when properly made and of either high or low carbon, within the limits of reasonably good commercial practice, is the most readily machinable commercial ferrous material.

2. Considerable difference of opinion now exists as to whether or not high-carbon malleable cast iron is more easily machinable than low-carbon metal. The problem is rather serious for, very obviously—since tensile properties, shock resistance, and so on, are determined primarily by carbon content, the lower carbon being the more desirable—if high-carbon metal does machine the more readily, then there is here an incompatibility between high strength, ductility, etc., on the one hand, and machinability on the other.

3. Such an incompatibility, if existant, would have to be reckoned with when writing specifications. To some interests, machinability is of greater importance than strength, while to others, the latter is the more important.

Opposing Viewpoints on Machinability

4. Let us examine first the *a priori* arguments on both sides of the question. The protagonist of the point of view that high carbon favors machinability reasons thus:

> First, carbon is the most important factor in determining any of the physical properties of malleable, and, since machinability is but the expression of a complex of other physical properties—strength, hardness, etc.—machinability must be also determined by carbon content.
>
> Second, obviously, if it be so determined, then the effect of carbon on the other variables is in such a direction in every case that the ease of machining is improved with rising carbon content.

5. The opposing side, even though perhaps granting the truth of the preceding contentions, offers in rebuttal the following:

> First, machining generally is confined, in practice, to a thin surface layer.
>
> Second, the composition of this layer is deter-

mined by the conditions of annealing, and not by the original composition of the iron.

Hence, the composition of the original hard iron cannot be the determining cause of the machinability ultimately observed, and so the issue is joined.

6. On the previous summary of the *a priori* reasoning, the advantage lies with those who say that machinability is determined only by annealing conditions, for they may grant all of the opposition's contentions without weakening their own position.

7. Some opportunity for reply, however, remains to those favoring the original carbon content theory. They may reply thus:

(1) Annealing conditions may produce such phenomena as deeply and completely decarburized surfaces, or pearlitic "picture frames," but we do not consider metal of that character to be normal and well-made malleable.

(2) All manufacturers are striving to reduce surface decarburization as inimical to machining, and this is now so far accomplished that machining is by no means confined to layers whose composition is the result solely of annealing conditions.

8. This disposes of the logical validity of the annealing contention by denying the premises upon which the conclusion rests, and it becomes a question of fact, not of reasoning, which point of view should prevail. Unfortunately, it has so far been impossible to get any well-informed user of malleable castings to state publicly and fully his observations on this subject, although at least one such investigation has been made in considerable detail.

9. At the risk of being considered an *ex parte* witness, the writer has undertaken the task of presenting the available evidence for the use of users and producers. His impartiality in the matter may be vouched for, perhaps, by the fact that some of his friendly critics have accused him of being alternately on opposite sides of this question.

PRELIMINARY CONSIDERATIONS

10. Lacking an authoritative statement of preference by a user who has studied the matter, perhaps we may be guided by current practice in determining what is customarily used by those who would machine the product readily.

Opinions of Manufacturers.

11. The writer is authoritatively told that two large consumers of malleable castings, who make a considerable percentage of their own requirements, manufacture metal toward the upper end of the commercial range of composition, say 2.60 per cent carbon and higher. Whether this is in the interest of machinability, cannot be said, nor is it permissible to name the concerns in question.

12. A friendly competitor says that certain of his trades requiring fairly difficult types of machine work cannot be satisfied with low carbon material.

13. A consumer in whose judgment the writer feels great confidence has indicated a preference for high-carbon material.

14. A French manufacturer of black-heart automotive castings for his own use finds it expedient, as stated on grounds of machinability, to keep carbon in the hard iron up to 2.60 per cent.

15. A distinguished British metallurgist who has had much contact with black-heart malleable castings has asked the writer whether the American industry did not experience considerable trouble from machining with metal so low in carbon as advocated for high tensile properties, a carbon content of 2.20 to 2.30 apparently being referred to.

16. On the other hand, many manufacturers can be found who say that their customers machine continuously and with satisfaction, material which as cast is in the range of, say, 2.20 to 2.40 per cent total carbon. Furthermore, no instances have come to the writer's attention of complaints as to machinability arising solely out of low-carbon castings in the sense that an occasional abnormally low-carbon heat is detected in the consumer's machine shop.

17. This, however, may be explained in part by the fact that such castings reach the customer mixed with others from many other heats, and therefore they are not readily detectable. The writer so far has not heard of anyone who definitely preferred to machine low-carbon malleable rather than high.

Evidence by Observation

18. None of this is scientific evidence, and yet a sufficient amount of such practical observation would constitute research by a trial and error method, compensating by multiplicity of

observations for lack of precision present in any single case.

19. A warning must be introduced here, however, that for such observations to be useful, they must be evaluated by the mathematical methods used by statisticians, and must be based on very large numbers of observations. Comparison of the results on a few specimens without proper mathematical background probably will prove valueless or even misleading.

20. Taking the preceding summary of opinion at its face value, it appears that certain presumably well-informed persons consider the higher carbons as beneficial; and that there remains some doubt as to whether the increase in carbon produces a visible improvement, but that none assert that high carbon reduces machinability. All this may be abbreviated still further in the statement that certainly high carbon is at least as machinable as any, and perhaps superior.

21. Were it not for the possible desirability of using low-carbon metal for considerations of strength, the discussion might well be considered closed by the preceding conclusions. However, since the lower carbons may be legitimately desired for other reasons, it becomes necessary to consider the question, "Does low-carbon iron machine with greater difficulty than high-carbon iron, and, if so, to what extent?"

EXPERIMENTAL POINT OF VIEW

22. When approaching the subject of machinability of malleable castings, we find the field so broad that it is necessary to determine how far we shall go in our investigation. Arbitrarily, the writer has chosen to deal only with normal malleable castings, and here again we must define what is to be considered a normal product for the present purpose.

The Normal Product

23. The term has been chosen mainly to exclude metal which is not, in a commercial sense, completely annealed. We are not interested here in some of the only partially annealed products now coming into occasional use, nor in the effect upon machining of metal accidentally so far under-annealed as to retain substantial amounts of combined carbon.

24. It is recognized that, speaking with strict accuracy, all castings contain traces of combined carbon; nothing in our definition is to exclude this and require a theoretically perfect metal. However, the "picture-frame" pearlitic rim and the pres-

ence of surface cementite occasionally described as a "surface shrink"—both of which are, in the author's opinion, ascribable to an equilibrium involving oxygen in the iron or carbide phase—are considered here to render the iron abnormal and beyond the scope of this discussion.

25. Nor is it intended to cover all the possible ranges of chemical composition, but only to consider metal of an analysis at least closely comparable with the usual. The effect of alloying elements is disregarded entirely in this paper.

26. It is considered that castings normally show a little ferrite rim at least, and unless this rim grows extremely wide or becomes distinctly oxidized in the grain boundaries near the surface, it is not regarded as an abnormality.

27. Lastly, we are not concerned with machining problems created by the presence (superficially or internally) of sand, siliceous slag, etc. Such contamination may be thought of as entirely accidental and equally likely to happen to iron of any composition, and hence may be thought of as irrelevant to the major issue.

28. These variables not considered pertinent to the main subject will be dealt with briefly at a later stage of this paper.

Experimental Determination of Machinability

29. Also, we must decide upon the experimental method of determining machinability. Here we will encounter great differences of opinion, and it may be as well to state in the beginning the reasons for choosing certain procedures.

30. No doubt machinability, to the user, means either cutting speed or tool life. The two are identical, for the latter is a function of the former and the machine-shop operator either wants to run very fast without an abnormal tool destruction or wants his tools to live long at good rates of production. The former probably is the more accurate statement of his desires.

31. Such tests as those of Taylor, and later of French and Straus, in which test logs of material are machined until the tools are destroyed, are suited to the direct attainment of the desired information. Unfortunately, the method of testing is scarcely applicable to the material with which we have to work.

32. To escape criticism we would have to use tools of a material similar to those used commercially, we must take only a surface cut of a depth comparable to commercial practice and

we must also use the customary feeds and cutting speeds. Within these limitations the tools would live so long that an immense amount of material—very many tons—would have to be provided for each quality of metal tested.

33. The difficulty of making a lot of uniform malleable "test logs" as hollow cylinders 4 to 6 feet long, 6 to 12 inches in diameter, of truly cylindrical section and of a thickness comparable to ordinary castings—say, ⅜ inch—is obviously so great as to exclude such a method of investigation.

34. A still better mode of attack might be a statistical investigation of tool life when machining, in actual production, castings of different composition. However, since tools customarily last for at least several hundred castings, and a number of tools must be dulled on each material tested in order to exclude accidental failures and permit of studies of probable tool life, such an investigation requires much time and a large volume of material of each kind to be tested.

35. So far, it has seemed impossible to obtain a co-operative set-up between a foundryman and a machine shop for making and publishing the results of such tests, although it is suspected that some of the concerns which both make and machine castings have gathered such data for their own guidance. We thus are left with no option but to adopt some form of laboratory test which is less time- and material-consuming than the destructive tests already mentioned. And here there will be as many opinions as to what constitutes an acceptable test of this character as there are engineers interested in the problem.

Available Laboratory Tests

36. The available laboratory tests are of two kinds: (1) Destructive tool test, in which early failure of the tool is brought about by abnormally high cutting speeds, and (2) tool load, in which the cutting properties of the metal are inferred from the stresses set up in the tools used in cutting.

37. The latter method is open to some philosophic objection, since it measures the property sought indirectly. It is believed, however, that there is now a fairly sufficient body of evidence to warrant a belief that, in the absence of abrasive quality in the material being cut (here excluded by limitation of our investigational field), there is a direct relation between tool stress, tool temperature and tool life at a given speed or cutting speed for a given life.

38. An exposition in detail of our reasons for such an assumption was presented before the A.S.T.M. in 1923.[1]

39. Assuming that we are to use a tool dynamometer as a means of measuring machinability, the question immediately arises as to what form the machining operation is to take and how the stresses are to be measured. Undoubtedly, the operation of drilling has been more thoroughly studied than any other operation. The stresses lend themselves readily to measurement, and expert designers have intensively studied the mechanism required.

40. Our laboratory is provided with an Olsen efficiency machine, which is admirably suited to making tests of this character. Unfortunately, we will be met at once with the objection that this machine, used to measure drill resistance, does not take cognizance of surface metal conditions. Logically, the criticism is unassailable, and the only proper defense is to prove, to those who believe *a priori* that the character of the surface metal bears no relation to the rest, that their postulate is wrong.

41. This point will be further alluded to later in the paper, although perhaps inconclusively. For the present it may be well to say that our principal reason for being satisfied with this form of test is entirely pragmatic.

42. As a matter of fact, the test works in the sense that changes of practice made to improve machinability as measured by drill testing have resulted in an increased satisfaction on the part of users of castings operating extensive machine shops.

43. Furthermore, an investigation of complaints regarding machinability has shown conclusively either that the drill test corroborated the complaint or that the castings were not normal as defined earlier in this paper. We rather question whether any machinability test could be devised which would measure the dulling effect of a sandy surface or of slag inclusions in a single casting, and we lay no claim to an ability to detect such conditions, except by chemical or metallographic evidence.

44. The reason for defining normality and excluding all but normal metal is, of course, in part to avoid argument as to the effect of abrasive constituents in the surface metal. In such materials there probably is no direct relation between tool life and tool load. The expedient is believed justified in our problem,

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[1] *"The Significance of Tool Temperature as a Function of the Cutting Resistance of Metals,"* Schwartz and Flagle. Proceedings, American Society for Testing Materials, vol. 23, pt. II, 1923, pp. 27-39.

for certainly none will argue that such materials would ever be other than unsatisfactory materials for machining, nor consider them as proper commercial malleable.

EXPERIMENTAL DATA

45. Assuming now that we are to express machinability in terms of drill performance, we may either measure the torque and thrust of a drill advancing at constant feed, or the feed and torque of a drill advancing under constant pressure. Experience has shown the latter to be the more convenient method of test, although both have been frequently used in this laboratory. For the present purpose, both methods of test were used.

The Problem Defined

46. The problem for solution is whether there is a relation between machinability and tensile strength in malleable. The tests were made upon the Olsen efficiency machine installed in this laboratory. It was decided to chart graphically both the

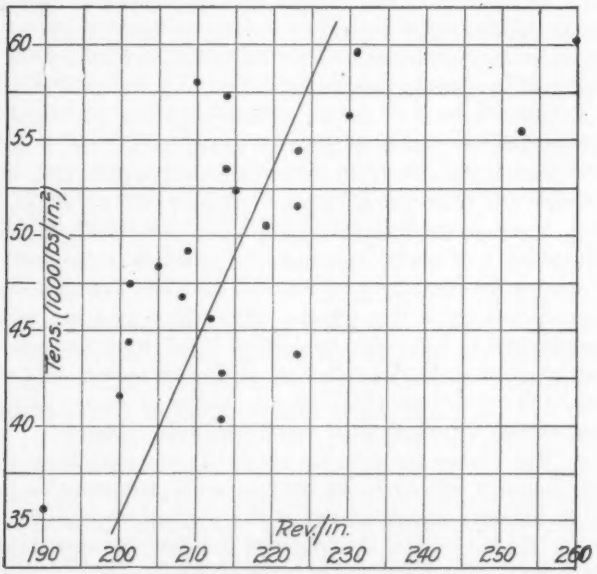

FIG. 1—AVERAGE TENSILE STRENGTH PLOTTED AGAINST MACHINABILITY FACTOR OF REVOLUTIONS PER INCH OF PENETRATION. EACH POINT ON GRAPH REPRESENTS TWO TESTS EACH ON AN AVERAGE OF NINE HEATS. (SEE EQUATION 1, PARAGRAPH 60).

penetration under a constant load of a standard drill penetrating the material at constant rate of rotation, and to chart also the torque of a similar drill driven into the material at a constant rate of feed.

47. Visual readings for torque in the former case, and for thrust in the latter, also were taken during the progress of the experiment. All of the experiments were conducted with high-

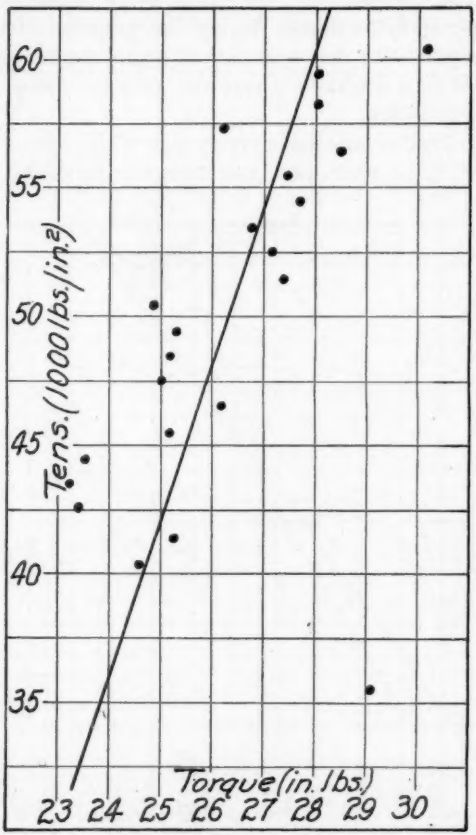

FIG. 2—AVERAGE TENSILE STRENGTH PLOTTED AGAINST MACHINABILITY FACTOR OF TORQUE IN INCH-POUNDS. EACH POINT ON GRAPH REPRESENTS TWO TESTS EACH ON AN AVERAGE OF NINE HEATS. (SEE EQUATION 2, PARAGRAPH 60.)

speed drills, ½ in. in diameter, made by the Cleveland Twist Drill Co., the drills not being ground during the progress of the experiment.

Conditions of Drilling Tests

48. The drills in each case were run at 240 revolutions per minute, which is a rate approximately correct for drills of carbon steel of this diameter. For feed under constant load, a gravity pressure of 220 lbs. was applied; the power feed was at the rate of 0.005 in. per revolution. The drills, being of high-speed steel, were found not to be dulled during the progress of the experiment, as evidenced by the constancy of result obtained by drilling from time to time a standard material with the drills being used for the investigation.

49. To further minimize errors due to the character of the drill used or to its wear, each specimen was tested by using four

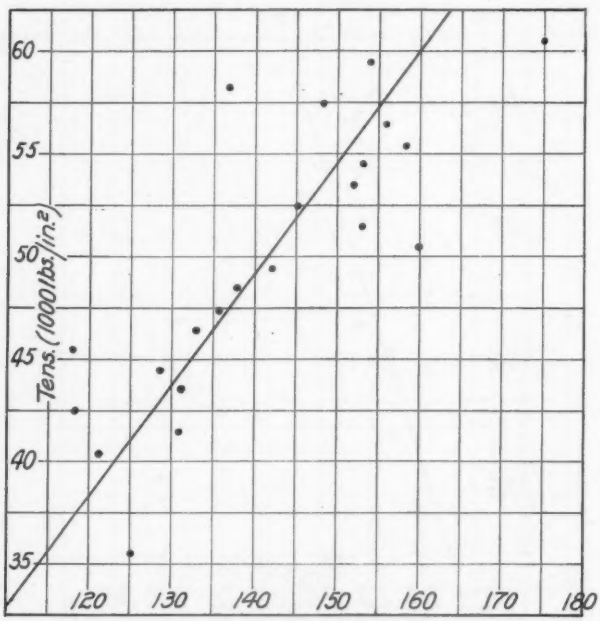

FIG. 3—AVERAGE TENSILE STRENGTH PLOTTED AGAINST MACHINABILITY FACTOR OF THRUST IN POUNDS. EACH POINT ON GRAPH REPRESENTS TWO TESTS EACH ON AN AVERAGE OF NINE HEATS. (SEE EQUATION 3, PARAGRAPH 60.)

different but supposedly identical drills. One pair of these test drills was used for the work with gravity feed, and another pair for work with power feed. In no case were the specimens drilled in the same order in each series with both drills of the pair, so that accidental errors due to wear, had they occurred, would have become noticeable.

50. The performance of the test drills was compared from time to time with the performance of a secondary standard drill on a homogeneous lot of malleable iron, and this secondary standard drill was checked at the beginning and end of the

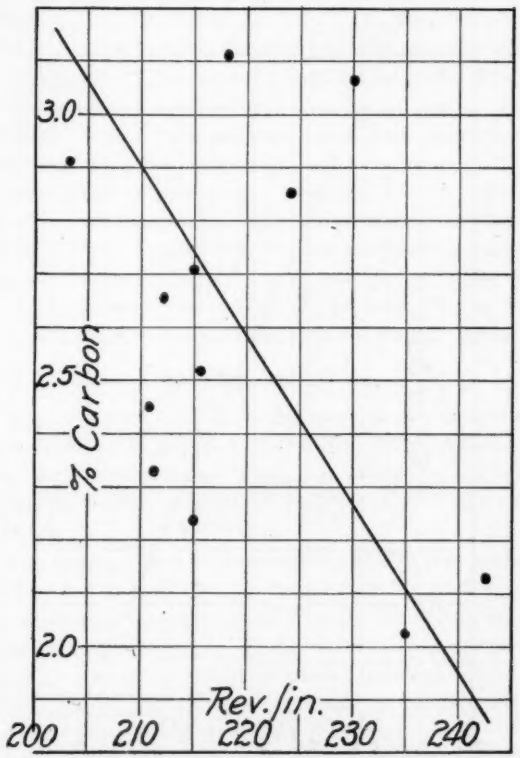

FIG. 4—PER CENT OF TOTAL CARBON BEFORE ANNEAL, PLOTTED AGAINST MACHINABILITY FACTOR OF REVOLUTIONS PER INCH OF PENETRATION. EACH POINT ON GRAPH REPRESENTS TWO TESTS EACH ON AN AVERAGE OF NINE HEATS. (SEE EQUATION 4, PARAGRAPH 60.)

investigation against the performance of a primary standard drill of the same size and form for this purpose only.

51. This somewhat elaborate checking up of the drills among themselves was originally deemed necessary, but, as already stated, the net conclusion was that the drills were not measurably dulled at any time during the investigation, and consequently the data obtained in checking may be disregarded in the present connection.

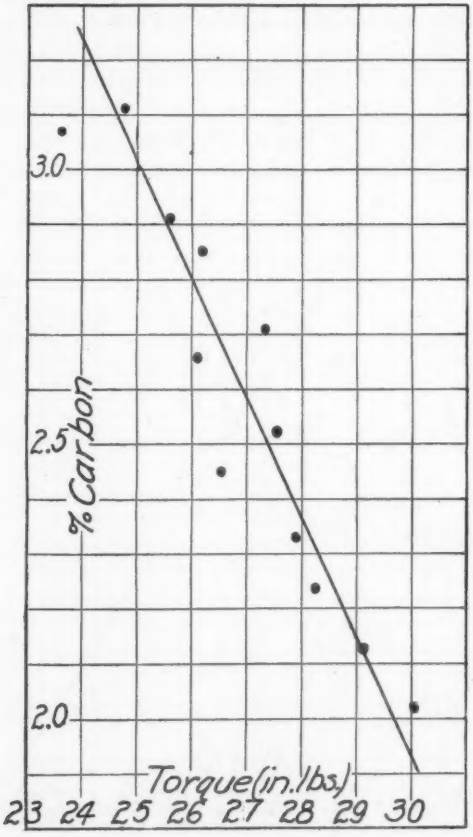

FIG. 5—PER CENT OF TOTAL CARBON BEFORE ANNEAL, PLOTTED AGAINST MACHINABILITY FACTOR OF TORQUE IN INCH-POUNDS. EACH POINT ON GRAPH REPRESENTS TWO TESTS EACH ON AN AVERAGE OF NINE HEATS. (SEE EQUATION 5, PARAGRAPH 60.)

Test Specimens

52. In order that the results might be affected as little as possible by an unforeseen characteristic of works practice at any one plant, the metal for this investigation was obtained from 14 malleable plants representing a wide distribution of foundries.

53. The chemical composition before anneal and the strength and elongation of each specimen were determined and reported to us by the plant furnishing the material. Shore and brinell hardness were determined in this laboratory. The drillings from each hole were collected separately and analyzed for total carbon.

54. Our thanks for this large amount of routine analytical work are due to the laboratory of the Indianapolis works. The metal submitted purposely varied greatly in quality, including some very-high-carbon iron made as stove iron, as well as some of the best available material.

55. The range in carbon was practically from 2.00 per cent to 3.10 per cent before annealing, the strength varying from a little over 35,000 lbs. to about 60,000 lbs. per square inch. About 125 heats were represented in the investigation. The data are naturally quite voluminous, and it has seemed wise in the interests of conciseness to present them only in graphic form.

Arranging Test Data

56. For this purpose the heats were grouped according to tensile strength, each group representing a range of 1000 lbs. per in.^{2} in tensile strength. Thus, for instance, all specimens whose strength is from 52,000 to 52,999 lbs. per in.^{2} constitute a single group.

57. The average rate of penetration at 220 lbs. pressure and torque and thrust at 0.005 in. per revolution for each group were then computed and the results plotted in the following figures. (See paragraph 60, below.) Each point thus represents two tests each on an average of nine heats, although the points in the middle of the strength range represent more than nine heats, and those near the ends fewer than this average.

58. Figs. 1, 2 and 3 show these average values of tensile strength plotted against the average of the three criteria of

[2] "*Malleable Iron Drilling Data*," Schwartz and Flagle. Transactions, Society of Automotive Engineers, vol, 17, pt II, 1922, pp. 729-748.

machinability just described and no doubt are self-explanatory. The lines shown on the figures represent the most probable relationships, by the method of least squares, assuming the relation to be rectilinear. This is pure assumption, but our information scarcely justifies any attempt to seek out a more complex relation.

59. Figs. 4, 5 and 6 are exactly similar to Figs. 1, 2 and 3, except that total carbon before anneal is the basis of the group-

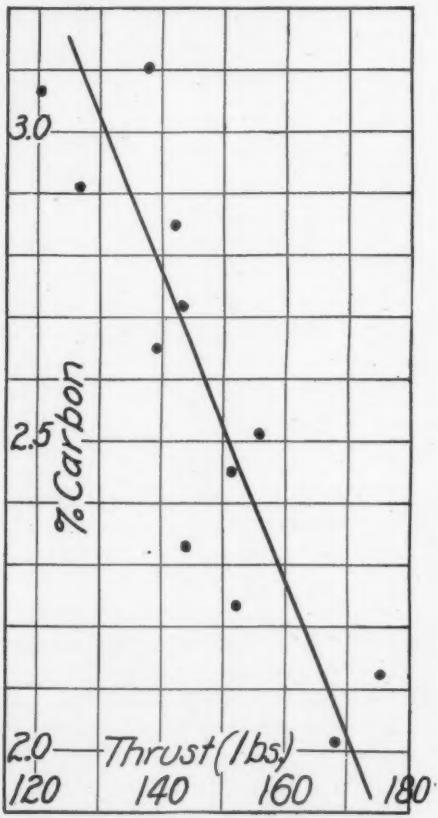

FIG. 6—PER CENT OF TOTAL CARBON BEFORE ANNEAL, PLOTTED AGAINST MACHINABILITY FACTOR OF THRUST IN POUNDS. EACH POINT ON GRAPH REPRESENTS TWO TESTS EACH ON AN AVERAGE OF NINE HEATS (SEE EQUATION 6, PARAGRAPH 60.)

ing, instead of tensile strength. The carbon in a given group is constant within 0.10 per cent.

60. The equations of the six straight lines are as follows, and represent the best simple relations which can be deduced from the data:

$$\text{Penetration}\left\{{}^{\text{rev.}}/_{\text{in.}}\right\} = 162.7 + 0.0010725 \text{ tensile}\left\{{}^{\text{lbs.}}/_{\text{in.}^2}\right\} \quad (1)$$

$$\text{Torque (in lbs.)} = 18.2 + 0.000161 \text{ tensile}\left\{{}^{\text{lbs.}}/_{\text{in.}^2}\right\} \quad (2)$$

$$\text{Thrust (lbs.)} = 64.59 + 0.001871 \text{ tensile}\left\{{}^{\text{lbs.}}/_{\text{in.}^2}\right\} \quad (3)$$

$$\text{Penetration}\left\{{}^{\text{rev.}}/_{\text{in.}}\right\} = 304 - 33.0 \text{ carbon (per cent)} \quad (4)$$

$$\text{Torque (in lbs.)} = 38.8 - 4.63 \text{ carbon (per cent)} \quad (5)$$

$$\text{Thrust (lbs.)} = 241.3 - 36.8 \text{ carbon (per cent)} \quad (6)$$

Some Considerations of Test Procedure

61. We have participated in tests to determine the machinability of surface metal by a method similar to that employed by Smith and Barr[3] by measuring the torque of a die cutting a thread on the material to be tested. Our experimental facilities were somewhat more elaborate.

62. There were prepared specimens of the desired metal in the form of hollow cylinders, about ¼ in. thick and 6 inches long. The cylinders had lugs at one end to facilitate holding them against turning. The specimens were ground before annealing, to a size which was estimated to bring them to the standard outside diameter of ¾ in. pipe, i.e., 1.04 in.

63. A No. 4 Pratt and Whitney ¾-in. pipe die was mounted on the fixed spindle of the Olsen efficiency machine. The specimen was rotated (40 r. p. m.) by the live spindle of the machine and its tapered end brought into contact with the chuck by a light gravity feed. This load was only sufficient to keep the center in the rotating spindle against the specimen, the die controlling the rate of feed.

64. It was hoped at first to use no lubricant. Perfect threads could not be obtained in this way, so a heavy stream of lard oil was pumped into the die automatically during the tests.

65. The friction, when turning a previously threaded specimen into the die by hand, was negligibly small. The specimens, although very well made, were neither quite round nor all of one size after annealing. All were micrometered in several places

[3] *"Relation Between Machining Qualities of Malleable Castings and Physical Tests,"* E. K. Smith and Wm. Barr. TRANS. A. F. A., vol. 28, p. 338.

and the observed torque was corrected, on the assumption (after Frederick Taylor) that the pressure of a chip is proportional to its cross-sectional area, thus—

> Corrected Torque: Observed Torque : : Moment about center of Cross-Section removed from Correct Specimen: Moment from Specimen of the Observed Diameter.

Effect of Carbon on Resistance to Threading

66. The analysis and history of the specimens was furnished by the foundry. Of each material, three specimens were annealed in a hot portion of the furnace, and three, cold. The data obtained, on five heats only, of varying carbon, are shown in Table 1.

Table 1

EFFECT OF CARBON ON RESISTANCE TO THREADING

				Torque on ¾ in. pipe die, inch-lbs.	
				Hot	Cold
Si	Mn	S	C	annealed	annealed
0.91	0.30	0.076	2.58	319	330
0.89	0.30	0.078	2.71	319	326
0.90	0.31	0.080	2.79	303	330
0.95	0.30	0.091	2.85	313	334
0.90	0.28	0.070	2.96	294	329

67. By the method of least squares, we may compute that the effect of an increase of 1 per cent in carbon is to reduce the torque a little less than 63 inch-lbs. for hot annealed, presumably more decarburized metal, or a little under 20 inch-lbs. for cold-annealed metal.

68. The threading data may be open, perhaps, to the criticism that too few heats are represented. Also, the pipe die exerts an end pressure owing to its conical shape, which may have contributed to the torque even though no friction was observable of the die on a finished thread. Furthermore, the thread no doubt penetrates below any decarburized zone.

69. The results are not offered as conclusive; but, insofar as they are worth anything, they are experimental evidence that surface machinability is not independent of the properties of the material as a whole.

Machinability in Terms of Cutting Speed

70. An attempt has been made in our laboratory to measure machinability directly in terms of cutting speed by a method recommended to us by H. J. French, then of the U. S. Bureau of Standards.

71. The specimen is in the form of a disk about 20 in. in diameter and about ¾ in. thick, having a central hole 2½ in. in diameter. It is centered in a lathe chuck, using particular care to see that the front surface is normal to the axis of revolution of the lathe. A cut is started from the center outward, hence at a uniformly increasing cutting speed, and continued until the tool fails. From the speed of the lathe and the diameter of the cut at failure, the cutting speed producing failure can be calculated.

72. If desired, the rate of rotation of the lathe may be reduced and the experiment repeated a number of times on the same disk. If it is desired to determine the difference between the surface metal and that within, the experiment may be repeated after completely facing off the disk.

73. The method is simple in principle but very difficult of execution. It is almost impossible to make specimens of this size and straighten them so perfectly that the front face can be made to run true. This difficulty we could never overcome except that, by laborious work and rejection of specimens which were not flat, a few suitable plates can ultimately be obtained.

74. Also, there must be a supply of tools all alike in shape and hardness and of one material, and these tools must be of a steel which will fail at a cutting speed within the experimental limits. The tools used in our experiments were drill rod of practically eutectoid steel, heated in borax to 850 degs. Cent. and water quenched. The ends were ground to a definite angle with the axis and the rod mounted in a definite position in a very rigid tool holder. After dulling, the flat surface (constituting the upper surface of the tool) could be reground, removing enough metal to get below the worn tool lip.

75. In view of these difficulties it proved impracticable to carry through any long program by this method. We did investigate a few specimens from different heats of each of two types of metal—here designated as *A* and *B*—known to differ by about 25 or 30 rev./in. in the drill test by penetration under constant load, type *B* being the more difficult to machine. (See Table 2.)

Table 2

MAXIMUM CUTTING SPEEDS UNDER TEST CONDITIONS

Spec. No. and type	Location	R. P. M. 13.0	17.6	23.4	31.2	42.0	Mean
B 02	Surface	54.5	55.3	63.7	62.8	60.6	59.4
B 02	Heart	....	83.4	80.6	79.7	79.8	80.9
A 22	Surface	....	....	73.7	74.6	63.6	70.5
A 22	Heart	....	76.8	94.3	82.7	80.7	83.8
A 19	Surface	64.7	68.25	66.7	61.4	66.0	65.4
A 19	Heart	....	98.0	....	92.0	92.0	94.0
B 7	Surface	50.25	53.0	53.6	57.15	63.25	55.45
B 7	Heart	.....	90.0	91.25	92.0	90.75	91.0
	Average of all	56.5	75.0	74.8	75.3	74.6	

The depth of cut was in each case 3/32 in. and the feed, 1/42 in. per rev.

76. Note that the cutting speeds to produce failure are all low because of the purposeful selection of a tool which would not stand high speed; the speeds, therefore, are not comparable with shop practice using tools of other materials.

77. We may summarize the mean value of Table 2 in Table 3, whence it appears that the difference in maximum cutting speed for the two types is greater at the surface than within and in each case is consistent, qualitatively at least, with the drill test results.

Machinability and Depth of Specimen

78. Lastly, we may quote here data from the beginning of an investigation into the change in machinability as we proceed from the surface into the heart of a casting. The tests were made in the manner provided for turning tests in the Olsen efficiency machine.

79. The specimens are hollow cylinders about $\frac{5}{16}$ in. thick, ground truly cylindrical before annealing. Of course, they warp and oxidize a little during annealing, so that the first cut removed is not quite uniform or concentric.

Table 3

MAXIMUM CUTTING SPEEDS

Type	Surface	Heart	Difference
A	67.9	88.9	21.0
B	57.4	86.0	28.6
Difference	10.5	2.9	

80. They are centered in the testing machine by a ball bearing on the pendulum spindle and a steady rest on the movable head and successive cuts about $\frac{1}{32}$ in. deep are removed with a feed of 0.005 in. per revolution, using a tungsten carbide tool to avoid dulling. From the recorded torque and the micrometered diameter before and after the cut, the tool load per 0.001 in. width of chip (0.005 in. thick) is computed.

Table 4

UNIT TOOL LOADS PER 0.001 IN. WIDTH OF CHIP (0.005 IN. THICK)

Layer No.	Specimen Nos. 7	9	10
	Unit Tool Loads		
Annealed Without Packing			
1	1.045	1.083	0.957
2	0.912	0.964	0.836
3	0.955	0.936	0.801
4	0.933	0.886	0.842
5	0.867	0.841	0.823
Annealed With Slag Packing			
1	1.038	0.980	1.080
2	1.029	0.870	0.896
3	0.847	0.846	0.836
4	0.924	0.942	0.826
5	0.913	0.819	0.806
Annealed in Ore			
1	0.841	0.970	1.053
2	1.028	1.042	0.970
3	0.870	0.922	0.749
4	0.890	0.840	0.778
5	0.897	0.888	0.829

81. Specimens were available of three different carbon contents, as follows:

Mark.	C	Mn	Si	S	P
7	2.30	0.42	1.17	0.054	0.166
9	2.38	0.35	0.99	0.065	0.162
10	2.85	0.37	1.05	0.051	0.159

and each annealed in three ways, (1) a 4.7-day cycle without packing, (2) a 4.7-day cycle in hematite ore and (3) a 7-day cycle in air-furnace slag. In every case the graphitization was entirely complete in a commercial sense. The unit tool loads were as shown in Table 4.

Conclusions Reached

82. Obviously, there is not yet a sufficient body of data to justify any very sweeping conclusions. It is obvious that, in general, the tool load decreases as we go further and further into the casting, the decrease being at first rapid and then rather slow.

83. Important exceptions are noted in the outer layers of specimens 7 and 9 annealed in ore, and occasional minor exceptions in the third layer, which are deemed unimportant for the present purpose and, possibly, due to shrinkages.

84. The last three layers usually are somewhat alike in tool loads on a given specimen; and, except for the fourth layer in the slag-annealed sample, and the third in ore where No. 7 and No. 9 specimens are interchanged, the tool load invariably is in inverse order as the carbon content.

85. Judging by the mean of the three inner layers, the differences in annealing condition have caused much smaller differences in machinability than the differences in initial carbon. In the outer layer the results are far different here (depending on the anneal chosen), the order of the three heats becomes very erratic and any one seems to have about an equal chance of standing best, intermediate or worst.

86. In the second layer, when the machinability does not run in inverse order as to the total carbon, the exceptions—which are not infrequent—are due to an interchange of specimens in a series in which no great differences in unit load ever exist.

87. The question of why heavy oxidation should have rendered the surface layers of Nos. 7 and 9 very easily machinable, is not here further elucidated, but attention is called to that fact.

DISCUSSION OF DATA

88. It is to be observed that all 14 plants contributing to the drilling investigation do not make quite the same range of carbon content, nor is the relation of carbon to tensile strength perfectly identical in all. This introduces a certain degree of irregularity and causes the points to scatter more than would be the case if all the material came from a single plant. The average relation, however, probably is a better guide to the facts than would be more concordant data from a single works.

89. The foregoing data have been used in part as the basis of an earlier publication.[2] The compilation just given, however, is different in viewpoint, and the quantitative evaluation is new.

90. From equations (2) and (3) or (5) and (6)—as given in paragraph 60—we may compute the energy per unit volume required to drill malleable cast iron, the chips being 0.005 in. thick. If L be the axial load on the drill, and T the torque, then the work done when the drill advances one inch is

$$W = L + \frac{2\pi}{0.005} T$$

and the volume of metal removed is

$$V = \frac{\pi}{16}$$

hence the work per unit volume is

$$\frac{W}{V} = \frac{L + \frac{2\pi}{0.005} T}{\frac{\pi}{16}} = 5.09\, L + 6400\, T \qquad (7)$$

91. Substituting for L and T their values in terms of tensile strength or carbon, as the case may be, and collecting numerical terms, we obtain

$$\frac{W}{V}(\text{in lbs.}) = 116{,}809 + 1.04 \text{ tensile} \left\{ {}^{\text{lbs.}}/_{\text{in.}^2} \right\} \qquad (8)$$

$$\frac{W}{V}(\text{in lbs.}) = 249{,}548 - 29{,}819\, C \left\{ \begin{matrix} \text{per} \\ \text{cent} \end{matrix} \right\} \qquad (9)$$

92. The equation for cutting energy in terms of tensile properties is considerably affected by the effect on equation (2) of the rather difficultly machinable group of low tensile strength at the very bottom of Fig. 2. This group, in turn, was largely affected by the results of a single plant. Mention is made of this fact for the reader's caution, although there seems no good reason for omitting the group.

93. The tests based on cutting speeds also are mainly of corroborative interest and seem to point rather clearly to the conclusion that drill testing, although perhaps not defensible on strictly logical grounds, is a fair criterion at least of machinability by other operations.

94. It had occurred to us that the failures of the tool might be related not only to cutting speed but to the total amount of work done during the cut in question. Owing to the greater mean radius of the cut, the amount of metal removed during the test at, say, 17.6 r. p. m., may be two or three times that at 42 r. p. m. If the amount of metal removed is a factor in tool life, the life should then decrease progressively with decreasing rates of rotation.

95. The average values at the bottom of Table 2 were included to determine this point. The average at 13 r. p. m. is meaningless, for it includes only tests showing relatively low cutting speeds and is hence not a good average. The averages of the other four columns are certainly alike within the limits of error of the experiment and confirm the applicability for the intended purpose of the method of testing.

96. It is unfortunate that the preparation of the specimens is so difficult. If we are willing to do without the possibility of re-testing a considerable number of times on the same surface, a somewhat thicker specimen of much less diameter would remove many of the difficulties. In any future work along these lines, this laboratory would possibly limit itself to about a 10-in. specimen, possibly machining both sides as a check.

97. The 45 observations made on turning operations in the Olsen machine admittedly constitute nothing more than a pilot experiment to determine what may be encountered in such an investigation. It appears that metal more than $\frac{1}{16}$ in. below the surface behaves (with regard to tool loads) in turning in a manner similar to its behavior when being drilled. This result is by no means surprising, for indeed it could not well be otherwise.

Machinability and Depth Below Casting Surface

98. Although the loads observed on turning the inner parts of the specimens vary somewhat with the annealing conditions, there is a general conformity to the rule that, for metal more than $\frac{1}{16}$ in. from the surface, the machinability is largely independent of depth and mainly determined by carbon content. The irregularities of results are believed to be due largely—perhaps entirely—to the presence of shrinks in the unfed specimens used in the investigation.

99. In the outer $\frac{1}{32}$ in. of the castings, the results are so erratic as to permit no general conclusions as yet. Observations are recorded showing that there are even well-marked exceptions

to the expected relations that the outer skin is more difficult to machine than the heart and that the difficulty of machining surface metal increases with the degree of oxidation thereof.

100. Particular attention is invited to the fact that any discussion of the surface machinability of malleable, even if completely graphitized, is apparently meaningless unless accompanied by some statement as to the amount of metal removed during the operations under discussion. This is due to the apparent lack of correlation between the machinability as measured as the first $\frac{1}{32}$ in. and on the third or subsequent $\frac{1}{32}$ in.

101. It is further noteworthy that, although for discussions of surface machinability the conditions to be observed in the outside $\frac{1}{32}$ in. are of major importance, yet measurements on this layer are precisely the most difficult. The depth of the first cut can scarcely be kept the same throughout, for there is always enough warpage in annealing so that the malleable specimens are no longer truly round or, perhaps, even truly straight.

102. It would probably be possible to center accurately a truly cylindrical specimen on its supports in the machine; but if the specimen be somewhat irregular, this is no longer possible, so that the chip is not of constant thickness. Roughening of the surface by oxidation, especially under drastic conditions, adds to this difficulty. With great care the variation in width of chip can perhaps be kept low enough so that the inertia of the machine damps out variations in torque arising therefrom; but if great care is not taken in the preparation of the specimens, very erratic tool loads may be observed.

103. If, on the other hand, one is interested in the removal of fairly thick layers—as we were in the case of the tool life tests, for instance—then the observations recorded point to the conclusion that the results will depend but little on the surface metal and greatly on that within, whose properties can be readily determined by the simple drill test.

104. It probably would be distinctly worth while to make observations under the best attainable test conditions as to the machinability of *thin* surface layers of metal.

ABNORMAL METAL

105. The subject of the effect on machinability of material other than normal as here described is worthy of comment.

106. The machinability of pearlitic material is affected just

about as is the machinability of steel, by increase in combined carbon. Layers of metal in which the matrix is preponderantly pearlitic throughout, machine with great difficulty. The cutting loads increase and the abrasive action of pearlitic cementite dulls the tools rather rapidly.

107. A little very finely distributed cementite is not noticeable in machining, and sorbite and spheroidized cementite also are of relatively little effect, representing dispersion of the hard phase in a form where it is not so effective in regard to cutting conditions.

108. Common experience, however, seems sufficient demonstration that metal containing any considerable amount of combined carbon will always produce fewer pieces per tool grind than the normal product. The writer believes that tool life will decrease even more rapidly than tool load increases.

109. The completely decarburized deep rim usually is considered to be "stringy" in machining, necessitating lower cutting speeds—not because of hardness but for the same reason that pure iron or copper do not machine readily. Tool wear is probably little affected, but the hourly output is decreased because of the reduced cutting speeds required to maintain suitable cutting conditions.

110. It may be mentioned that, in the writer's experience, abnormally heavy ferrite rims are a predominating cause of complaint by users, followed next by pearlitic metal. Very poor machinability, when referable to the metal itself, is nearly always due to one or the other of these factors.

Sand and Slag

111. It would seem unnecessary to say that leaving sand on a casting, or slag inside it, will rapidly abrade the edges of tools to the point where they will cease to cut. Sand or slag in the surface is, of course, a cleaning rather than a metallurgical question, yet the foundryman will do well to remember that no imperfectly cleaned casting is really readily machinable.

112. The writer has been told of an instance where tool life was decreased to one-third its proper value by carelessly cleaned castings which, however, were not noticeably dirty. The fault is observed more often in boring than in turning operations, due to the greater difficulty of inspecting the interior of holes than the outside of castings.

113. A very effective means of testing the cleanliness of surface quantitatively is to take a thin cut over a surface of measured area, collect all the chips and volatilize all the iron in a current of dry and oxygen-free chlorine. The residue remaining will contain, among other things, all the sand and slag which were in the chips. The residue may be ignited to remove carbon and extracted with dilute HCl to remove the metallic oxides and manganese chloride, and the residue weighed as siliceous matter.

114. To those who have not tried the experiment, the results may be somewhat of a surprise. It may be urged upon those interested in cutting tests on the original surface of castings, that cleanliness of surface is not to be overlooked as determining tool life.

CONCLUSIONS

115. The data submitted leave no room for doubt in the writer's mind that, as measured by drill testing, the machinability of malleable is very largely determined by carbon content, as are its other physical properties.

116. The turning tests reported at least are fairly well in line with this conclusion, so long as the amount of metal is not too small, but are not in themselves voluminous. The threading tests are of general interest only and cannot be given too much weight.

117. It is believed that future investigations of surface machining operations removing considerable thicknesses of metal will not be productive of much new information, but that tests which remove layers of the order of magnitude of a few hundredths of an inch may be very instructive. The commercial applicability of such tests will depend upon whether or not the production operations remove layers of similar thickness.

118. For the reasons enumerated in the body of this paper, investigation on the machinability of surface layers, to be of value, must be conducted with very unusual precautions to insure cleanliness of surface, uniformity of thickness of cut and accuracy of measurement of tool loads which are, at best, small.

119. A statistical inquiry into tool life must cover voluminous data and must be evaluated by proper mathematical methods.

120. The writer would be much gratified if those having data on any aspect of the problem under consideration would contribute such facts or well-founded opinions as they may have

in the form of a complete discussion (preferably written). The purpose of the present paper is primarily to stimulate such an interchange of ideas as will result in the best possible mutual understanding of the problem.

SUMMARY

121. This paper was written primarily as a means of promoting discussion of the question as to whether there is any incompatibility between high strength and easy machining of malleable by those having actual knowledge on the subject.

122. Data are given showing that, as measured by drilling, the machinability of malleable is determined primarily by carbon content.

123. It is recognized that drill tests are not necessarily equivalent to tests which remove surface metal only. Turning tests are described which tend to corroborate the findings of the drilling tests with the limitation that the cut be not too thin.

124. The data available seem to show that the machinability of *thin* surface layers does not conform to any simple assumption and should be separately investigated before conclusions are possible.

125. Attention is called to the necessity of very precise laboratory conditions in any such investigation.

126. The value of a statistical investigation on a large scale under machine-shop conditions *and by suitable mathematical analysis* of the data, is pointed out. Discussion is earnestly solicited on the various points brought out in this paper.

DISCUSSION

ORAL DISCUSSION

E. M. RICHARDSON:* Has anyone paid any attention whatever to the raw materials that went into the stock? The discussion has all been on analysis, but nothing has been said of the amount of pig iron, scrap and various materials which produce the metal. It would strike me that that would have a very large effect upon the machining quality.

W. R. BEAN:† I have been quoted in one of the discussions. My opinion today is the same or perhaps a little stronger than it was at that time, that the difficulties in machining are from the annealing process and not primarily from the carbon content of the casting.

---

*The Austin Co., Chicago.

†Grindle Fuel Equipment Co., Harvey, Ill.

It is no doubt true that there is a difference in drilling as shown, but this operation is not the operation that sends castings back to the producers. Castings which come back from machining troubles come back because there is no carbon—or a very small amount—in the material that is being removed. It more nearly resembles a wrought iron, perhaps, than anything else.

Over a period of many years we dealt with fine threading, and it has always seemed to me that that must eventually be the measure which determines the machinability of malleable iron—something that works only in the surface; possibly a milling cut would serve.

One thought in connection with an amplification of the drilling test is to completely decarburize a section the same as those used in the drilling test and measure the machinability by the drilling operation on a malleable product which has no carbon present. Then we will be dealing with the material that is dealt with in most of the machining operations.

I believe that it is practicable to prepare specimens in that manner by very careful treatment in the annealing to avoid excessive oxidation, by which I mean scaling or anything of that kind, and to anneal at a moderate temperature rather than at a high temperature, repeating the process long enough to obtain a section that is without carbon. I would like to ask Mr. Schwartz what thickness of section was used.

H. A. SCHWARTZ: They are longitudinal.

W. R. BEAN: Mr. Schwartz and I have discussed this thing time and time again and have worked together on it for many years. The specimen for a threading test should be ground in the hard iron to an exact dimension and everything carried out in the most painstaking manner in the preparation of the specimens.

D. E. WILLARD:* In the castings that we are machining, the floor-to-floor cost of machining is hardly ever to exceed 10 per cent of the cost of the casting—the cost in our own shop. I think the entire discussion of the difference in machinability should be considered with that thought in mind.

For instance, we have some castings that cost us 25c to produce. They are, by the way, hub castings, on which the actual floor-to-floor cost is only two cents. On a casting that costs us 60c to produce, our floor-to-floor cost is only four cents. That does not include, of course, burden in the shop, but is the actual labor. On a casting that costs us 80c to produce, our floor-to-floor cost is five cents. That is the actual time cost that is paid for the machining operation, not including power, heat, light, supervision, etc.

I believe that on the average casting not more than 50 per cent of that from 8 to 12 per cent floor-to-floor cost would be affected by a difference in machinability. Thus, when we get through with the entire discussion, how much could be saved by the difference of 10 to 15 per cent when that 10 to 15 per cent applies probably to only four per cent of the cost?

*Danville Malleable Iron Division, Danville, Ill.

WRITTEN DISCUSSION

W. F. GRAHAM:* The author is to be complimented on the carefulness of his experimental work and his clear and thorough conclusions. The effect of composition and strength of malleable cast iron on its property of machinability is of prime importance to all producers and consumers who are interested in obtaining in this material a balance of properties, of which machinability is not the least in importance.

In paragraph 88, the author mentions certain irregularities in his relations of carbon content and tensile strength. We find that our averages of tensile strength and his carbon content substituted in his straight-line curves in Figs. 1 and 4, respectively, check within four revolutions per inch, or within 1.8 per cent. This is a most satisfactory agreement.

In order to arrive at his conclusions, Mr. Schwartz has adopted methods of evaluation that lend themselves to accurate interpretation from the laboratory standpoint, but they are not the yard sticks by which the property of machinability is judged in the machine shop.

In obtaining his values for torque, thrust, etc., he has made constant those factors that the machine shop may make variable, particularly in hand-drilling operations. So long as the motor will pull, the factor of torque is of no particular interest, but the criterion will be: How fast can a given hole be drilled or how many pieces per hour can be produced with reasonable tool life?

The above remarks are not intended to discount the author's data or

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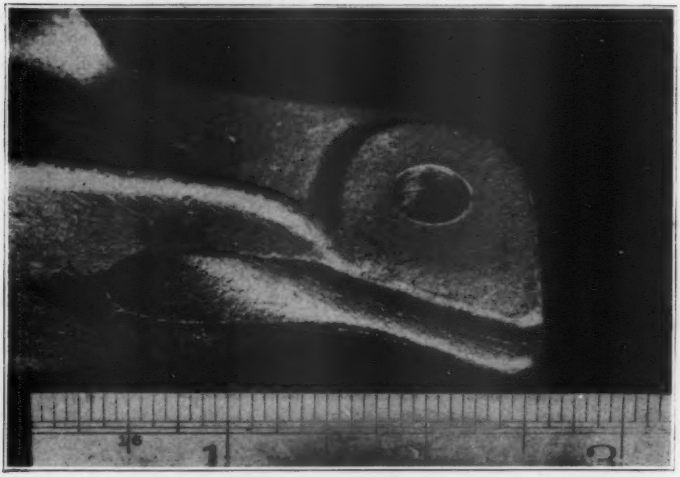

FIG. 7—CASTING WITH SINGLE DRILLED HOLE. DRILL PASSES THROUGH TWO SURFACES.

Table 5

MACHINABILITY OF MALLEABLE IRON

Fig.	Patt. No.	Size of H. S. drill.	No-load spindle speed, r. p. m.	Dist. drilled, in.	No. of surfaces drilled.	Peripheral speed, ft. per min.	Travel, in. per min.	Revs. per in. drilled.
7	15350	25/64	1420	1/2	2	146	7.15	199
8	4040	5/16	1692	1/4	4	138	6.75	250
9	14674	5/16	1480	21/32	4	121	10.09	146

conclusions, but we will present some actual time-study data in relation to the machinability of our iron, from the machine shop point of view, for comparison with that of the author.

For experimental reasons, the author chose certain values for constants in his tests which we consider abnormally low. His spindle speed was 240 r.p.m. and his feed was 1.2 in. per minute of drill travel.

We will present the results of time studies made on three drilling operations on three different castings, as shown in Figs. 7, 8 and 9. The iron has a carbon content of 2.60 to 2.65 and an average tensile

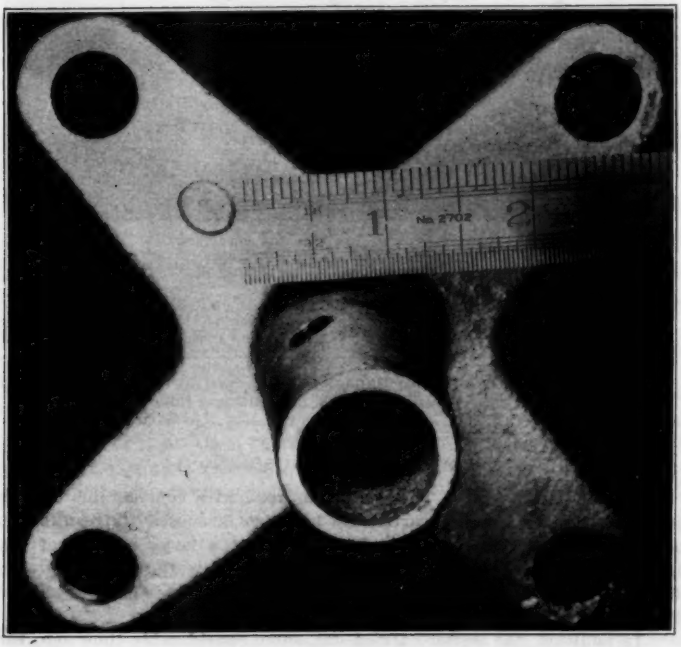

FIG. 8—CASTING WITH TWO DRILLED HOLES, AS SEEN IN THE HUB SECTION. DRILL PASSES THROUGH FOUR SURFACES.

strength of 45,000 to 50,000 lbs. per sq. in. Table 5 gives the factors surrounding the machinability.

From the standpoint of the factors which the author has used to measure machinability, he has shown that the higher-carbon irons are more easily machinable than those of lower carbon content. This comparison probably would be even more effective if the speeds and feeds were of an order of magnitude comparable to those used in practice for the latter material.

We believe that iron having a tensile strength of 45,000 to 50,000 lbs. per sq. in. has a balance of desirable properties, including machinability.

The writer is indebted to L. R. Stalder of our Manufacturing Department for the time-study data used in this discussion.

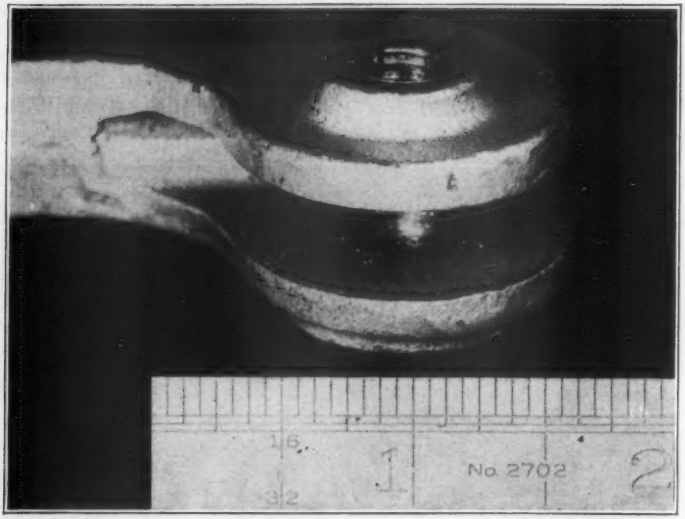

FIG. 9—CASTING WITH DOUBLE DRILLING OPERATION. TOTAL TIME-STUDY DATA COVER THE TOTAL OPERATION OF DRILLING BOTH HOLES.

WRITTEN DISCUSSION

T. MCLEAN JASPER:* The writer has read with considerable care the paper written by Mr. Schwartz. He has also discussed its results with several men associated with the machining of a large number of malleable castings, such as are used for the automobile industry, as well as with the supervisors of this product in our plant. These men agree with the findings of this paper.

In addition, the writer carried out, some considerable time ago, very

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extensive tests on specimens such as come in the normal way from the producers of malleable castings, some of which specimens were not specially prepared for testing and some of which were specially prepared compositions to give a greater range of carbon content and also a greater range of tensile strength. Both of these sets of test specimens bear out the findings of Mr. Schwartz.

The writer is keenly aware of the interesting controversial nature of this problem and had occasion very recently to come under the intensity of its heat. He desires, however, to avoid being associated with either side of this controversy except in so far as the effects of high and low carbon or low and high strength malleable castings has affected the degree of soundness and machinability which has occurred throughout the experience of his own company when purchasing such castings from a variety of sources.

For small mallable castings which are sufficiently intricate in design to require considerable care in producing soundness as well as machinability, and in which strength of material from which the castings are made is of a lesser value than the strength and uniformity of the finished casting, we have found that the lower-strength, higher-carbon malleable gives

(a) more uniform and less difficult machining operations,
(b) greater freedom from shrink zones, and
(c) when tested to failure in the shape as used, a much more uniform strength quality with less very low values.

It might be said that the designs which are considered here are such as do not require a material of great strength if homogeneous conditions are found in the casting.

It is true that shrink cracking can be reduced by proper design and chilling, but the question always arises in the writer's mind as to why a high-strength material should be used which is difficult to machine when, also associated with such stronger materials, there are some undesirable shrink problems for which there is no economic gain by the use of this strength.

There are probably a great many uses for the higher strength castings, but the user of a particular group of castings should not be compelled to adopt a material which does not suit his particular job.

This suggests that at least two specifications for malleable castings should be adopted: One, where the question of strength is most essential and which is simple in design, and one in which strength is of less value but in which great homogeneity for intricate shapes as well as machinability is desirable.

WRITTEN DISCUSSION

L. J. KELLY:* It is with interest that I have listened to the various papers read thus far. The conclusions reached by Mr. Schwartz in respect to the difference in machinability between low and high carbon

*Superintendent, Fort Pitt Malleable Iron Co., Pittsburgh.

iron are not in harmony with the results I have found to be the case, after a very lengthy practical experience.

I would point out that laboratory tests are, at times, very useful indeed. It would appear certain to me, however, that it would not be the part of wisdom to use such a test, if the true answer to the problem can be determined as easily through a diversified number of service tests, under varied conditions.

The only justification for the use of such a test is when service tests take a prohibitive length of time to be carried through—such, for instance, as the accelerated corrosion tests and these are not translatable into what actually might be expected in service under conditions that might vary somewhat from the conditions used in the laboratory test.

From what Mr. Schwartz has stated, he does not appear to have any too much faith in his own results, as far as their reliability in predicting what service tests might show on the same samples. He rather sidesteps machining operations other than boring, and seems to be not too sure about that.

Something must be wrong somewhere when laboratory tests indicate one thing and lengthy service tests something very different.

At the plant where I earn my daily bread, our experience justifies me in having views just the contrary to those entertained by Mr. Schwartz. My conclusions are based not only upon the machining operations in our own plant, but also on those of our customers, and it may prove of interest if various cases were cited. For example, 2¼ inch grease plugs were cast from a hard iron of about two per cent carbon. The following were the machining operations:

Two cuts to remove ¼ inch of stock; an undercut both front and back in one operation, after which the plug was threaded for a distance of ⅝ inch. Regarding tool life, 500 were machined every 22 hours (day and night) with but one grinding of tools. Twenty thousand were threaded with but three grindings of the chasers, the grinding necessary being very slight.

This was and is being regularly done in our own plant, and while other cases could be cited, it might prove of more interest to learn something regarding our observations at customer plants.

In addition to the plug that I have brought here to show you, I have also a differential casting, known as the "bird cage." These castings are machined by the factory at high speed for production. Our castings were submitted and we were told that they machined even more easily than those from other sources of supply. As, at the time, we were one of but a very few who were making a high-tensile product, it is not unfair to assume that the other sources of supply were making a product in accordance with the S. A. E. specification.

As it would prove tiresome to multiply instances, I will simply state that to date we have never received complaints regarding machinability that were based upon high-tensile strength. Such complaints as have been received always have been traced down to faulty surface conditions, due to sand and scale.

Regarding the discussion paper by Mr. Jasper, it seems hard to reconcile some of his statements with actual facts, and I can but conclude that he has had but little experience with a high-tensile product. His one statement alone that a high-tensile product cannot be made as uniformily as one low in tensile properties, I can deny through actual experience covering many years, but distinctly within the past four years, during which period one carbon has averaged about two per cent and the variations have averaged close to five points.

If Mr. Jasper can cite a case where anyone running on a low-tensile product has done better, I would be obliged to have the information. If he can be so far away from actual facts in this instance, I am afraid that he has little justification for the other claims that he has made.

WRITTEN DISCUSSION

T. MCLEAN JASPER: *(In reply to some of the points brought out in written discussion of L. J. Kelly):* It is with reluctance that I again enter the controversy with reference to the machining of malleable castings. I desire, however, to point out that the machining operations cited by Mr. Kelly do not enter into the controversy so as to produce in my mind the experience he so elaborately defines.

The experience cited by the writer covers automatic machining operations on malleable castings which accomplish as high as eight machining operations per casting at the rate of 420 per machine per hour. These cover drilling and facing operations.

Four automatic machines turning out finished castings at the above rate each, over a period of several years, give very much larger experience of machining than he has cited. These machining operations cover castings from a great number of manufacturers, and a fairly wide range of strength.

This experience on practical production operations bear out the results of Mr. Schwartz' paper. Mr. Kelly, therefore, will be obliged for the information he requests.

WRITTEN DISCUSSION

R. E. BRYANT:* Mr. Schwartz is to be congratulated upon his very instructive and illuminating discussion of the factors affecting machinability of malleable iron. There is hardly a matter of greater significance to the producer and the user of malleable iron than the definite clearing up of the confusion of thought that has surrounded this subject.

The writer's own company produces a substantial quantity of malleable-iron castings and, in addition, purchases appreciable amounts from a number of producers. All of these castings are machined by us, and machinability is of great importance to us.

In the early days of my connection with the Jefferson Union

*Vice-President, Jefferson Union Co., Inc., Lockport, N. Y.

company, the malleable iron which we were then purchasing had a tensile strength of about 32,000 lbs. per sq. in., whereas today our own castings as well as the castings which we purchase have a tensile strength of about 54,000 lbs. per sq. in. On all comparable operations, our machine speeds today are far higher than those of twenty to twenty-five years ago, although then, as now, we used high-speed steel tools.

We have found our machinability improving at a rate more rapid than our tensile strength. This is stated without any intent to dispute the results found by Mr. Schwartz. We realize that steady progress toward the reduction and elimination of abnormalities referred to by the author—better tool design, the use of stellite, tungsten carbide and other relatively new tool materials at certain key points—have all contributed to this result.

It would appear that Mr. Schwartz has provided a definite indication that variation in carbon content does affect machinability on interior cuts. It further appears that his tests are inconclusive for skin cuts and for threading cuts, which are largely skin cuts.

There is little question that skin cuts, or cuts which are predominantly skin cuts, are the most important for production machining operations. We know the constant effort made to reduce the amount of finish allowance to a minimum in order to save weight. Furthermore, on a large percentage of production machining operations, the threading operation controls the total time, especially on automatic machinery.

Thus the effect of the variation in interior cutting speeds which results from variations in analysis, is bound to be materially diluted by the effect of the skin and threading cuts where the tests reported proved inconclusive.

Probably there is very little commercial production of normal malleable iron outside of the range of strength from 40,000 lbs. to 60,000 lbs. per sq. in. and 2.00 to 3.00 per cent carbon. The total variation between these limits would appear to be only 15 per cent, based on the strength calculations, or something under 20 per cent based on the carbon calculations, whereas there is a 20,000 lbs. per sq. in. variation in strength per square inch, which is 40 per cent of the mean strength indicated above.

Thus it is apparent that the relatively small variation in machining characteristics developed in this paper may be far outweighed, from an economic standpoint, by other factors; and the writer has endeavored to get together some evidence of the economic relationship of the various factors involved.

In general, the value of the rough casting to the user far overshadows his true machining cost. Thus, if, by virtue of changing from a unit strength of 40,000 lbs. per sq. in. to a unit strength of 60,000 lbs., he was able to save a proportionate amount of metal, the saving would be many times the penalty of 15 per cent in machining cost indicated by this paper for interior cuts, and disregarding the fact that this percentage would be substantially modified by the effect of skin and threading cuts. Heavy castings undoubtedly are much more valuable in proportion to machining cost than are light castings.

Next, we must consider the fact that only the actual cutting time will be affected by this change in quality of material, and that the actual cutting time is substantially less than the over-all or floor-to-floor time. Undoubtedly it will be found that the ratio of actual cutting time to over-all or floor-to-floor time is smallest on light castings and largest on heavy castings, under production conditions.

From the above statements it is clear that, as castings get heavier, the relative advantages of a higher strength material increase. And the writer believes that a careful study by any producer who is in a position to take advantage of higher unit strength by lightening the casting, will find it distinctly advantageous to use the higher-strength material for castings beyond a certain weight.

However, the user who has heavy castings which he is not in a position to modify in weight to take advantage of high unit strengths, and who has deep cuts where machining time is a large relative factor and skin effects a relatively small factor, must bear in mind the fact that iron of lower unit strength and higher carbon is not suited to heavy section work, because of the danger and perhaps the certainty of primary graphitization with resulting weakness, and a strength in the casting far below test-bar results.

It thus would appear that, if there is any field for high-carbon, low-unit-strength malleable iron because of its higher machinability, we must look for it in the smaller, lighter casting where there is little or no danger of primary graphitization, and where machining costs are a larger factor in relation to casting values.

On this class of castings, however, we are faced with the fact that actual cutting time is a relatively smaller proportion of total machining cost; that depths of cut are less; that the skin effect becomes very much more important, and in a large proportion of the castings becomes predominant. Thus we have the constant dilution of the 15 to 20 per cent gain in machinability indicated by the test results, first, through the relatively large proportion of handling, indexing and tool-withdrawing times compared to actual cutting time; next through the increased importance of the skin-cutting effects, and then through the possibility, in many cases, of capitalizing the higher unit strength through weight reduction.

In the writer's judgment, a careful analysis of representative castings along these lines—using the figures indicated in Mr. Schwartz' paper as a basis for judging savings in interior cutting-operation times, with suitable modification of these figures where skin cuts are involved—will show that it is relatively unlikely that there will be any final net saving through use of the higher-carbon, lower-tensile material, and that the gain in production per day from given machine and tool equipment will seldom reach five per cent, if the figures given in the author's paper are a reasonably true indicator of relative machinability.

As against this very small gain in machine shop production, the user must weigh the fact that he is using a substantially weaker material with less ductility and shock resistance and, in general, a lesser degree of reliability.

Some may say they have experienced greater gains than this five per cent, but the writer believes that a thorough analysis would reveal the existence of abnormalities in the slower cutting iron "A." Such abnormalities are purposely disregarded in this discussion, because not inherent to high-strength or low-carbon iron.

In conclusion, I want to second Mr. Schwartz' plea for a more comprehensive study of this subject. We should clear up this "bugaboo" and evaluate the factors involved. Such a comprehensive study of the factors affecting machinability should be supplemented by an economic interpretation of the results from the standpoint of the casting user.

WRITTEN DISCUSSION

J. H. LANSING:* Mr. Schwartz' paper is well written and interesting, as his papers always are. Considered from the standpoint of the commercial-production machining of malleable castings, however, we must not lose sight of the fact that we have to deal, not with deep machining and drilling (from which the conclusions of the subject paper are mainly drawn), but rather with the surface 1/16 in. or 1/32 in. only, and never to exceed 3/32 in.

In general, when we speak of high-speed production machining, we consider the fast, light, commercial cuts referred to above. This commercial-production machining was what Mr. Touceda had in mind when, in November, 1927, he stated in M. I. R. I. Bulletin No. 183:

> "The writer's contention has been and still is that, provided all other factors aside from carbon content are as they should be, it is annealing conditions that will determine the cutting properties of the metal rather than the amount of carbon in the hard iron." (Mr. Touceda presented supporting data)

This commercial-production machining was what Mr. Schwartz had in mind when making the statement contained in Vol. 36 (1928), A. F. A. TRANSACTIONS, p. 818, from which we quote as follows:

> "The reason for presenting something which in print looks like rather abtruse physical chemistry, is very briefly this—a great many of us know, as Mr. Touceda has pointed out to us, that the machinability of the casting depends very largely upon the machinability of its surface since, in general, machine operations are surface operations and not deep machine operations from the body of heavy sections."

W. R. Bean referred to the same light-production cuts with which we are most concerned when he made the statement found in Vol. 36 (1928), A. F. A. TRANSACTIONS, p. 821, from which we quote:

> "For many years the thought has been with us that annealing was of vastly greater importance to the machinability of malleable iron than the original composition of the metal itself. It is of considerable satisfaction to me personally to have the matter brought out as it has been, because it was so difficult for me to get the idea across to those who had different ideas on the question."

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*General Superintendent, Danville Malleable Iron Div., Allith-Prouty Co., Danville, Ill.

We find, therefore, that three authorities above quoted are in agreement on the fact that, when the customarily light commercial production cuts are taken, the original carbon content of the metal is of substantially no importance. This is further substantiated by the experience of the company with which the writer is connected in its Hardware & Machine Division, where considerable production machine operations are carried on.

We are producing castings with large surfaces which must be machined to the 1/1000 part of an inch and yet are cast with an allowance of only 1/32 in. finish. We know also of other manufacturers machining large quantities of malleable castings where only 1/32 in. is allowed.

When discussing high- and low-carbon malleable-iron castings, by high carbon we refer to carbon in the upper ranges of from 2.50 to 2.90, provided primary graphite is absent; low carbon covers the lower ranges of from 2.00 to 2.40. The higher-carbon iron produces castings which will run about 45,000 lbs. per sq. in. in strength, or less, and up to 10 per cent in elongation.

In the case of the lower-range-carbon irons, however, the ultimate strength runs to about 55,000 lbs. and the elongation to 20 per cent and better. Surely the interests of both the producers and users of malleable castings are best served by the high-quality material.

To refer specifically to Mr. Schwartz' paper, there is mention (paragraph 11) of two large consumers of malleable castings making a considerable percentage of their own requirements and manufacturing metal in the high ranges of carbon. Anyone familiar with the melting and annealing operations of the larger of the two manufacturers mentioned should not seek further for reasons for running high-carbon metals.

Cupola melting with metal in direct contact with fuel necessarily makes for higher carbon content. The subsequent considerable reduction of carbon by cold steel additions to the electric furnace is, of course, a time- and power-consuming and otherwise expensive operation. It is not difficult, therefore, to understand why high carbon is favored at this plant, particularly as it enables them to take somewhat greater liberties with their annealing process when running at capacity.

What applies to the above manufacturer applies also to foundries whose metallurgical operations are similar in nature. Their attitude in any discussion on carbon content, therefore, is certain to be somewhat influenced.

In paragraph 81 of the subject paper, we wish to caution against considering the iron dealt with as being of normal composition. Particular reference is made to the manganese content, which certainly is abnormally high, especially in the case of the No. 7 iron, of which the manganese content is 0.42.

In summing up, the speaker would say that the drilling tests are certainly of interest but not to be taken as criteria by which customary commercial production machining may be measured, that no disadvantages of lower-carbon-range, high-physical-property iron have been brought forth, and that in view of its very marked advantages, its

production is certainly to the benefit of the malleable industry and of those whom it supplies. Between material of about 8 to 10 per cent elongation and 45,000 lbs. ultimate, and material of 20 per cent elongation and approximately 55,000 lbs. ultimate, there should be no question as to desirability.

The progress of our industry in devoloping physical properties from about five per cent elongation and 35,000 lbs. per sq. in. ultimate strength to the present A. S. T. M. specification of 10 per cent elongation and 50,000 lbs. per sq. in. has been remarkable. In addition to incorporating this elongation and ultimate-strength specification, the yield-point specification of the Malleable Iron Research Institute is now 32,500 lbs. and would easily permit of additional increase. Appreciating as we do the efforts being made to advance other industries, would it not be suicidal to deter the progress of our own?

We would like to see a comparison of commercial machining of malleable with other materials, as we believe this will be much more to the adantage of our industry than the drawing of fine distinctions between various grades of malleable, particularly when these distinctions are neither in line with nor based on practical quantity-production use of the material. Such an investigation would be of real value if conducted by someone with the facilities and ability of Mr. Schwartz.

WRITTEN DISCUSSION

O. W. BOSTON:* I am interested in Mr. Schwartz' paper primarily because of the methods used in obtaining the data from which the conclusions were drawn. I have had no experience in testing the machinability of malleable cast iron. The material on which the measurements were made, however, is just one of the several variables involved in the problem.

Malleable cast iron is first cast to form in the foundry and is then heat treated in order to produce the desired physical properties before any machining operations. It seems to be granted that there are three structures involved, namely, the material as it exists after being cast, the interior of the material after it has been heat treated, and the surface of the material after it has been heat treated. These three conditions exist regardless of whether the carbon content is high or low.

In considering the author's subject of "opposing viewpoints on machinability," it would seem to me that both viewpoints should be considered jointly rather than separately. In order to understand one's product, all possible information regarding it should be known.

Most mallable-iron castings upon being machined are, say, turned and faced. This may involve rupture only of the surface layer. For operations such as drilling, boring, tapping and possibly threading—all of which involve cutting below the surface—the interior of the casting after heat treatment must be considered.

Obviously, the material being machined is a heat-treated product,

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and so far as machinability is concerned, the casting in its original state might well be left out of consideration. On the other hand, chemical analysis might show that the three different materials would differ, and also their properties might differ. The opinions of manufacturers seem to run toward complacency as a result of no particular trouble, rather than satisfaction with the results of some well-directed program.

It is not the writer's intention to be critical of this particular group of producers and users, as the same situation exists in many other lines of industry. The metal-cutting industry thought it was getting along fine in many of its production jobs, until the introduction of the satisfactory tungsten-carbide tools. It was pointed out and shown to them that, instead of operating on a 100 per cent efficiency basis as they could do with the new material, they were actually well down the scale into inefficiency.

The author has presented very clearly the many complex problems involved in the study of the machinability of malleable cast iron.. The available laboratory tests for the determination of machinability are summarized in paragraph 36, under two headings: (1) Destructive tool tests in which early failure of the tool is brought about by abnormally high cutting speeds, and (2) tool load in which the cutting properties of the metal are inferred from the stresses set up in the tools used in cutting.

Personally, the writer would divide the second heading into four new headings, as (a) the force, energy or power required, (b) the cutability as applied to the drill under definite load, (c) the cutting temperatures developed, and (d) finish.

The author states in paragraph 37 that the tool-load method is open to some philosophical objections, since it measures the property sought indirectly. The writer would disagree with this statement in that he believes the destructive tool tests may really give the machinability of that particular tool shape, material and treatment, rather than of the material being cut, so that two factors are involved, the tool and the work.

Under the tool-load tests referred to, the tool is usually constant in shape throughout the tests, so that all deformation occurs in the metal being cut. The force, energy, power, etc., therefore, are direct functions of the material being cut for that particular tool. Unfortunately, the author has not given detailed measurements of the drills, so that comparison with other work is not possible.

There appears to be no scientific information available to show a consistent relationship between the machinability of a material as determined by the tool-life method and the machinability of the material as determined by the force, energy or power method. We naturally concede the point that a material like brass, aluminum or dow metal cuts easily and gives a long tool life, but when we consider many materials having similar properties, proof (or even practice) is lacking to prove the point.

It would seem to the writer that the heat-treated malleable iron

under consideration might well be tested for both the surface and interior body of the metal by suitable tests. A single-tooth milling cutter mounted in an impact-type testing machine has been used by the writer for determining the energy required to remove a given chip.

An apparatus set up on a large planer as constructed by the writer in a laboratory at the University of Michigan also makes it possible to observe through a microscope at any desirable magnification the cutting action, and, at the same time, the cutting force can be measured. The depth of cut could be made small or large to suit the requirements of this particular material.

Obviously, the drill-penetration tests and the drill-torque and thrust tests, as used by the author, measure only the machinability of the metal on the interior of the casting, as observations could not be made during the time the outer skin is being penetrated.

The experimental data offered in the paper may be subject to criticism, as follows: In Fig. 1, in which the revolutions required (for a drill under given load) to penetrate one inch are plotted opposite the tensile strength, the points are shown well scattered. It is indeed difficult to arrive at any one curve through these points.

If, for instance, the four points lying on or to the right of 230 revolutions per inch are disregarded, the remaining points might indicate a practically vertical line. On the other hand, if the four lowest points were disregarded, the balance of the points might indicate a line passing upward to the right at an angle of 45 degrees.

Again, the group of points above 50,000 lbs. per sq. in. indicate one curve, and the points below 50,000 lbs. per sq. in. indicate a second curve. Certainly, the general conclusion drawn is not favorable to any selected group.

The same criticism might be made of the data shown in Fig. 2. If only those points above 52,000 lbs. per sq. in. are considered, one line is indicated which is nearly vertical. For the group of points below 52,000 lbs., a second vertical line farther to the left is indicated. If the lowest three points are omitted from the lower group, a third line is indicated, and so on. In Fig. 3 the group of points above 50,000 lbs. indicate, by themselves, no general trend.

Fig. 4 is perhaps outstanding in that, by omitting the two lowest points having the highest revolutions per inch, a curve would be indicated by the remaining points, extending upward to the right instead of upward to the left as shown, which reverses the conclusion drawn. Comparing Figs. 4 and 5, it naturally would be suspected that the greater the torque, the greater would be the number of revolutions of the penetration drill to penetrate one inch.

This relation has been shown by the writer (*Transactions* A. S. S. T., vol. 16, November, 1929). On this line of reasoning the equations given by the author in paragraph 60 appear to be questionable.

The threading tests, it seems, would be more reliable if American-standard, fine-threads (because of shallow cuts) were used instead of the tapering pipe threads which introduce added difficulties.

In conclusion, the writer wishes to commend the author on his

treatise of this complicated subject dealing with an apparently complex material. The contents of Mr. Schwartz' paper indicate that a great deal of work has been done. It is apparent, however, that the results are complicated and, in the writer's opinion, do not lead to definite conclusions. This undoubtedly points to the fact that much more work must be done before the factors of machinability of malleable cast iron are definitely understood.

WRITTEN DISCUSSION

ENRIQUE TOUCEDA:* The author deserves the hearty thanks of this body for his painstaking attempt at a fair and impartial exposition of the situation, for his efforts to present the facts in quantitative form, for the great amount of work involved and particularly for his bringing this much disputed point to a head. It is frankly acknowledged by him that tests to give the same information as obtains under actual operations are impractical to carry out, with which opinion the speaker is in full accord.

Of what commercial value, then, are the results that have been presented?

In carrying out these tests the author was not actuated by curiosity but by a laudable desire to ascertain if there could not be found some particular composition of annealed product that could be machined at a worth-while higher speed than those of a higher or lower carbon content—a matter that would be of prime importance to the manufacturer, for machining properties in many cases are the governing factors in the cost of the finished casting.

However, as far as carbon *per se* is concerned, not only (as has been pointed out by the author) does the carbon vary from surface inward—a variation that the writer has found continuous for an average depth of 11/64 in., but it should be made clear that in an annealed casting of disproportionate sections, a thin section will contain a lower carbon content than one that is thicker. If, therefore, we are to believe that the carbon content is such an important factor as to affect speed in machining, surely the machine-tool speed for boring operations should be regulated as for the thinnest section to be bored.

For example, the writer has found that, in the case of thin fittings from a hard iron with around 2.65 per cent carbon, a carbon content is obtained in the annealed casting of around 0.50 per cent, while from 1-in. sections cast from a hard iron with carbon around 2.00 per cent, a carbon content results in the annealed casting that will average about 1.85 per cent.

Does it not seen significant that the author, in order to determine whether or not a high-carbon product can be machined at a higher speed than one lower in that element, has deemed it essential to resort to delicate laboratory tests?

If, through commercial operations, the manufacturer after a number of years' experience has been unable to satisfy himself regarding the

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correct answer, what can one reasonably conclude? If the manufacturer to whom this matter is so important has been unable to settle this question in his own mind, one way or another, it would appear to the writer that, if actually there is any difference in machinability between the two products, it obviously must be so very slight as to be of inconsequential importance, for if of consequence, that fact for economic reasons would have been discovered quickly and would have ceased to have been controversial long ago.

While Mr. Schwartz is able to quote from some manufacturers that a low-tensile product machines more easily than one of higher strength, the writer has had the assurance of a substantial number that this is not their experience. Aside from this, the writer has devoted much attention to this matter at plants where a high-tensile product is made and where a great deal of it is machined at the plant itself.

At a certain manufacturing plant visited by the writer within the past month, the rate-setter had based the rate on castings from a source of supply that does not run on a high-tensile product. The order had been divided and part given to a plant that runs on a product very high in tensile properties. No trouble is being experienced in the boring operation, and it was not found necessary to decrease the machine speed and alter the rate. Regarding this particular work, the following can be stated:

A 1-15/32 in. drill was being used and run at 256 r. p. m., which is one more revolution than the maximum recommended by the maker. This corresponded to a surface speed of 106 ft. per minute, and 0.008-in. feed per revolution. At another part of the same casting, a drill of 1-3/32 in. was boring a hole at 326 r. p. m., corresponding to a surface speed of about 90 ft. per minute, with a feed per revolution of 0.008 in.

It is unnecessary to multiply the instances that could be cited in which it has proved to be a matter of no moment to the manufacturer, from a machinability point of view, whether he is receiving a low- or high-tensile product.

Based upon what is known about the machinability of ordinary gray-iron castings, it might at first sight seem perfectly logical to assume that the higher the percentage of uncombined carbon in any ferrous product, the more easily it can be machined. However, in the making of comparative machinability tests in the case of malleable iron, there are numerous factors to consider other than carbon, that the author has ignored.

In the making of a high-tensile product—say, one with a total carbon in the hard iron of about 2.00 per cent—the usual and proper practice is to see that this carbon content is accompanied by a silicon of 1.10 to 1.20 per cent. It has been found that those elements that enter into solid solution with ferrite, such as silicon and nickel, facilitate machinability in malleable as well as gray iron. It must be borne in mind that in the low-tensile, high-carbon products the silicon content should be restricted to a percentage that will insure against the presence of primary graphite in the castings, for which reason the silicon must be kept relatively low.

Another fact which, in the speaker's opinion, is most important to consider, is that, other conditions being equal, a product containing 0.18 per cent phosphorus and 0.08 per cent sulphur should machine more easily than one in which these elements, respectively, are 0.13 and 0.05 per cent, a matter that should be taken into account when making comparative laboratory tests.

The writer believes that failure to consider these details will explain, in part, why the graph of Fig. 1 shows three groups of about 41,500, 44,500 and 47,500 lbs. ultimate strength, respectively, that took an average of 201 revolutions; and three on the other side of the line of probable relationship of a lower average ultimate, that average about 212 revolutions. Also, there are two groups of an average of about 57,500 lbs. ultimate that averaged about 212 revolutions.

The writer believes that this lack of consistency is easily explained by what he has set forth regarding the effect on machinability of the elements referred to. The same remarks he believes apply with equal force to the graph of Fig. 2.

If this is not the situation, then either the apparatus or the product must be considered temperamental. But, even in the case of a high or low product, it would be most misleading to draw conclusions from the carbon content of the hard iron, as it is the annealed and not the hard-iron castings that are machined. For this reason the writer sees no value whatever in the author's graphs of Figs. 4, 5 and 6, as they furnish no useful information.

It is to be regretted, therefore, that Mr. Schwartz did not omit these graphs and furnish instead the composition of the annealed samples, which would have admitted of a more accurate analysis of the value of the comparative data submitted by him.

Also, it would have been more satisfactory, the writer believes, if, in the graphs of Figs. 1, 2 and 3, the author had grouped his bars as per carbon content instead of ultimate strength and had plotted the carbon content against the three criteria instead of the ultimate strength; it is of common knowledge that, due to unsoundness or other factors, the ultimate strength may be the same in the case of some of the bars, and the carbon content quite different. The author must be aware that it does and can happen that the ultimate strength of duplicate bars from the same mold may be two or three thousand pounds apart and even more.

In reference to graphs of Figs. 4, 5 and 6, it is stated that the carbon in a given group is constant within 0.10 per cent, a matter of no apparent importance; but, as inferred, it would have been of importance to have known the conditions in respect to carbon in graphs of Figs. 1, 2 and 3.

Inasmuch as the author states that all of the annealed bars were analyzed, it is not clear as to what use this information was put.

The author states that about 125 heats were represented in the investigation, and that the range in carbon was practically from 2.00 to 3.10 per cent. If such was the composition used in the specimens for the boring tests, the speaker would question the absence of primary graphite in the specimens in the higher carbon ranges, unless the speci-

mens were very thin on the one hand or the silicons very low on the other.

If very thin, for obvious reasons this would tend to make the comparative results less accurate, while the same would obtain, for reasons already given, if the silicons were very low, as must have been the case in the event that primary graphite was absent. It is to be regretted that, in an investigation of this importance, complete data in respect to carbon were omitted and the dimension of the specimens that were bored not furnished.

It might be of interest to state that, in the writer's capacity of consulting engineer for the Malleable Iron Research Institute, castings that have proved hard to machine are at times sent to his office, occasionally by customers and again by members of the institute, in order that he can report on the cause of the trouble. The fact is significant that in such a lengthy experience as has fallen to his lot, among the very large number of these samples sent to him, there has not been a single one that he has found had been hard to machine due to a low carbon content, or what ordinarily would constitute a high-tensile product—omitting, of course, those cases in which there existed a surface metal deeply and quite completely decarburized, a condition obviously not unique in a high-tensile product.

The castings to which reference has been made invariably show that the trouble experienced was occasioned by one of the following defects: Some character of frame; the presence of shrink in the path of the tool; the castings not completely malleableized; sand or scale on the surface of the casting, or deeply decarburized surface metal. Surely no one would contend that such troubles are more prevalent in the case of a high than a low tensile product.

Machine tools, in many instances, are so designed that every operation that is to be done on a casting is carried through on the same machine, whether it be turning, slotting, facing, threading, boring or tapping. Perhaps the last two must be executed at the slowest speed, and consequently the rate-setter must base his rate on the speed at which it is commercially practical to carry through the last-named operations.

However, if the matter is to be considered from the standpoint of great refinement, and the casting is of disproportionate sections, the rate must be set for the speed with which the thinnest section can be bored, as this will be lower in carbon than the heavy one, and consequently the heavier section is being bored at a slower speed than possible were conditions different—a proposition that would hold true for all the other operations as well.

While statisticians have found the application of the theory of least squares to be practically indispensable to their needs, the value of this theory is dependent upon the amount of data under consideration and, in a measure, the closeness with which the groupings occur that are under consideration.

In view of the few number of points and their rather wide divergence, it is the writer's opinion that had Mr. Schwartz drawn by

eye the line in each graph that represents the most probable relationships, he would have come about as close as through the employment of the theory of least squares.

The writer would go on record as stating that, irrespective of whether a high-carbon annealed casting can be machined slightly faster than one of low carbon content, there is a very grave matter that the manufacturer should consider that far outweighs any slight apparent advantage in the machining of one malleable product over another, and that is the matter of primary graphite.

Asking your indulgence if the writer again refers to his rather lengthy experience with malleable-iron castings, he would point out that when castings have been sent to his office in order that he report regarding why they had failed in service, he has found that by far the larger number of failures have been due to the presence of primary graphite. This is an ailment to which the low-tensile product is very prone and one to which the other product is practically immune.

Without wishing to detract from the value of the author's work, in view of the fact that the tests were comparative, the writer believes it would have been in the interest of accuracy had the author plotted the graphs of Figs. 1, 2 and 3 as has been pointed out, as well as have taken into consideration those elements that operate for or against machinability.

Of one thing you may all be sure: The writer has no axe to grind. His sole thought here is as it always has been—to work for the best interests of the industry as a whole.

REPLY BY AUTHOR

H. A. SCHWARTZ: The author is gratified that his paper has been the cause of so much discussion, but disappointed in that those contributing have so largely concerned themselves with matters outside the scope of his investigation.

The original paper does not pretend to say what kind of iron should be made by a manufacturer. For this there is a good reason: The answer varies with the requirements of the user.

If this subject is to be studied, it must be in greater detail than by Mr. Bryant, who fails to consider that a reduction in section affects only the iron cost of the casting, which may be one-fifth of the total; that machinability as measured by drilling may bear a relation to cutting speeds more complex than a direct proportion; that some castings cannot be further lightened, and that many persons regard foundry losses as a function of carbon content. Given sufficient data, the problems can be answered, but only for specific cases.

Mr. Lansing criticizes the author for the omission of data which might have been found by consulting the first reference and which bear no relation to our present problem.

Those who have stated with great emphasis that low-carbon malleable can be readily machined merely agree with the first sentence of our discourse without adding to our knowledge. The author is

definitely of the opinion that only those in a position to quote strictly comparative data need be listened to on the question of commercial machining, and he himself, lacking such information, prefers to remain silent and take no sides.

In this connection the question of very thin cuts may be of extreme importance, and the author definitely disclaimed conclusive data on this subject, nor has he heard of any others possessing more specific data.

Prof. Boston, by long association with experimentation in cutting of metals, is in a position to contribute much of fundamental importance with regard to methods of investigation. If, as we have heard, he is about to become associated with the Malleable Iron Research Institute in the field of machining investigation, very profitable results are to be expected. So far, Prof. Boston has conservatively confined himself to a discussion of the author's methods and data and has expressed no original opinions on the question under discussion.

It is not clear to the author why Prof. Boston says, "The writer would disagree with this statement . . . . . that the tool-load method is open to some philosophic objections since it measures the property sought indirectly," when in the next paragraph he says, "There appears to be no scientific information available to show a consistent relationship between the machinability of a material as determined by the tool-life method and the machinability of the material as determined by the force-energy-power method."

In the face of this apparent contradiction we are not sure of his attitude on tests of the dynamometer type. His suggestion that a cutter mounted on an impact machine may form a useful means of measuring surface machinability is valuable if tests of the "force-energy-power" type are admissible. We have considered this procedure but have not constructed the necessary equipment, although we agree as to its probable utility.

Prof. Boston points to the omission of a description of the form of the test drill. It was a standard 1/2 in. diameter, high-speed Cleveland Twist Drill Company drill, which probably identifies the form although it does not describe it. For completeness, the following may be added:

Helix angle, degs. 27-1/2
Point angle, degs. 118
Clearance angle, degs. 12
Thickness at point, in. 0.071
Thickness at periphery, in. 0.344

Prof. Boston then proceeds to a criticism as to the straight-line relations between the two variables assumed as basic. It is not believed that the available data justify any more complex relation. There seems absolutely no reason to assume such a discontinuity in the relation at any particular point as Prof. Boston tries to introduce by arbitrary grouping of data, nor does the writer find evidences of such grouping consistently throughout the several graphs as would seem necessary to substantiate such discontinuities.

It thus appears necessary to postulate a smooth curve, in which case a straight line has the merit of simplicity. It will be noted that we do not insist upon a rectilinear relation, but do not regard the data as adequate to substantiate a more complex form, and hence use the simpler.

The criticism of Fig. 4 by Prof. Boston is interesting. This is the only discrepancy in our data proving the poorer machinability of high-carbon iron. If we accept the critic's suggestion and omit the two lowest points, the slope of the line is reversed and then becomes consistent with all other data.

We ourselves did not feel justified in suggesting the omission, lest we be criticized for selecting data to prove our point. It is not evident that Prof. Boston's discussion has altered the general conclusion that strong iron is more difficult to machine, below the thin surface, than weak iron.

Professor Touceda points to an unfortunate omission in the author's text, which we hasten to rectify. The specimens investigated were the grip ends of the test bars whose physical properties were reported. These were drilled longitudinally on their axes by the 1/2 in. drill, no surface metal being included. The drilling records for each cut were sufficiently uniform to suggest the absence of shrinkage in the specimens, and the tensile fractures were in each case free from notable shrinkage and similar defects. If there is any better way in which we could have assured ourselves of the fact that the metal drilled was identical with that pulled, we are open to suggestions.

In spite of his intimate contact with the problems, Prof. Touceda gives no comparisons on a quantitative basis of the machinability of strong and weak iron. Prof. Touceda asserts that "elements such as silicon and nickel facilitate machinability." The writer is told by several persons that S. A. E. 2512 nickel-steel machines less readily than such straight-carbon steels as 1010 or 1015. He himself has had greater difficulty in shaper operations on four per cent silicon low-carbon steels than in the absence of silicon, and it is probably generally known that the addition of manganese and chromium—both of which can form solid solutions in ferrite—to low carbon steel is slightly detrimental to cutting.

The addition of silicon to low-carbon steel increases its hardness and lowers the ductility, as those know who sell low-carbon cast steels under the A. S. T. M. specifications. Further, the assertion apparently contradicts the best substantiated principles.[4]

Prof. Touceda's assertion is so unusual that it would appear that the burden of proof rests upon him, and that his statement should be supported by experimental evidence.

It is readily admitted that other variables than carbon affect the machinability of malleable, among which may be counted chemical composition with regard to other elements, hence the "scatter" in results. We should like to investigate these in detail but find the task beyond our present ability. That neither the metal nor method is tempera-

[4]Jeffries and Archer, *"Science of Metals,"* p. 254.

mental was concluded from the consistent behavior of the standard metal used throughout the tests to verify the condition of the drills as explained in the text.

The purpose of the statement that in Figs. 4, 5 and 6 carbon is constant within 0.10 per cent—which Mr. Touceda considers meaningless—is obviously to describe the experimental conditions.

The author chose to investigate the relation between initial carbon content and machinability; his critic may, if he chooses, regard this subject as unimportant. The curves speak for themselves in showing to what degree the two factors are correlated. Mr. Touceda prefers a correlation between carbon after annealing and machinability, while he himself says, "in the making of a high-tensile product—say, one with a total carbon in the hard iron of about two per cent . . . . . "—thus recognizing that ultimate strength is to be controlled by initial total carbon.

The reason for seeking a correlation of initial total carbon and machinability will be readily understood to be that initial carbon content is the variable which the manufacturer controls to produce the desired tensile strength.

The reason for not including the final carbon content may well be here explained. It was originally thought that, in the series of samples, under-annealed metal might exist. All the combined carbon contents, however, were found in the usual short range around 0.05 per cent, and this factor was therefore dismissed.

The total carbons after anneal were, of course, always somewhat lower than the initial values; but since a consideration of their values would neither decrease the scatter nor alter the conclusions, and since the total carbon of hard iron can be more accurately determined than that of malleable, due to precision of sampling, it was deemed needless to prepare formal data involving carbon after anneal.

We cannot understand Mr. Touceda's suggestion that "it would have been more satisfactory . . . . . if in the graphs of Figs. 1, 2 and 3 the author had grouped his bars as per carbon content instead of ultimate strength . . . . . ". This has been done and the results are shown in Figs. 4, 5 and 6, to whose existence he objects in his succeeding paragraph.

The author is not in accord with Mr. Touceda's view that it is not worth while investigating, by refined methods of measurements, variables not commercially detectable, else why do any laboratory work?

Lastly, Prof. Touceda ventures the unsupported statement that the method of least squares is inapplicable to the analysis of a limited mass of statistics. A study of "Empirical Constants," page 130 *et seq.* of Merriman's "*Method of Least Squares*," is suggested to those readers desiring a competent mathematical opinion.

The author, although desiring to limit his closure to the smallest possible compass, has felt constrained to reply to certain criticisms he regards as not well founded.

Effect of Heat on the Permeability of Natural Molding Sands

By Walter M. Saunders and Walter M. Saunders, Jr.,
Providence, R. I.

Abstract

The change in permeability on heating molding sands from various districts has been studied. A simple device for measuring permeability at temperatures up to 1000 degs. Cent. has been constructed. The "hot" permeability of a sand is different from the permeability usually measured. The effect of steam and expansion of the sand grains on permeability is demonstrated. In general, molding sands from various districts act in a similar way on heating.

Introduction

1. A question often asked is, "What does molten iron do to a molding sand? Does heat destroy its properties or can the sand be used over again?"

2. It is well known by those working with molding sand in the foundry that heating will destroy the "life" of a molding sand, if the sand is heated to a more or less degree. This life is partly indicated in comparable figures by the A. F. A. standard bond or dye-adsorption tests.

3. The effect of heat on the property of venting or permeability is not well known. It is, however, known that molding sand, when used over and over again, does not have the same permeability as when new. We have been for some time trying to design a simple and easy way to determine the effect of heat on the permeability. Finally the apparatus, to be described later, was constructed.

Meaning of "Hot Permeability"

4. The term "hot permeability"[1] has been suggested to describe the permeability of molding sand at temperatures similar to those in the mold. That there is a difference between hot permeability and permeability at room temperature, has been suspected for some time.

[1]E. F. Wilson, *Some Experiments on Sand Control.* Transactions, A. F. A., vol. 38 (1929), p. 183, p. 569.

5. The purpose of this paper is to present the results of some permeability tests made at varying temperatures on green molding sand. At a future date the completed results on core, dry sand and green sand with sea coal will be given.

DESCRIPTION OF APPARATUS AND METHOD OF TEST

6. The apparatus used is illustrated diagrammatically in Fig. 1. To the A. F. A. standard permeability device was attached a metal tube 2 in. in diameter and 2 in. long, the lower end being closed by a rubber stopper with a hole in center, through which passed one end of a ½-in. glass tube bent at right angles. The other end of the glass tube was connected by a rubber stopper to a 1-in. silica combustion tube 24 in. long.

7. The silica tube served to hold the sand to be tested and was placed in a carbon combustion electric furnace, so as to bring the sand at the middle of the heating unit. At the outlet end of the silica tube, or the end opposite the permeability device, was inserted a thermocouple. Otherwise, that end was open, offering no resistance to the passage of air or steam from the tube.

8. The thermocouple was so placed that it nearly touched the core of sand in the tube. In this way the temperature would be slightly different than if it were obtained at the center of the core of sand. The temperatures of the various tests are comparative, since the thermocouple was always in the same relative position and the heat was applied at approximately the same rate for all tests.

Standard Permeability Method Not Used

9. The standard method for permeability was not used, for the reason that the large amount of moist air—2,000 cc. passing through the silica tube for each test—would tend to complicate the determination of the pressure, especially at the higher temperature. The 0.5-mm. orifice was finally adopted as it required a very small amount of air for the test with, consequently, slight disturbance of the equilibrium in the silica tube.

10. The total amount of air passing through the tube by the orifice method during the entire run was about 1,000 cc., and, since as many as 75 trials or tests were made, the volume for each test was extremely small.

11. The core was formed by using a modified type of the

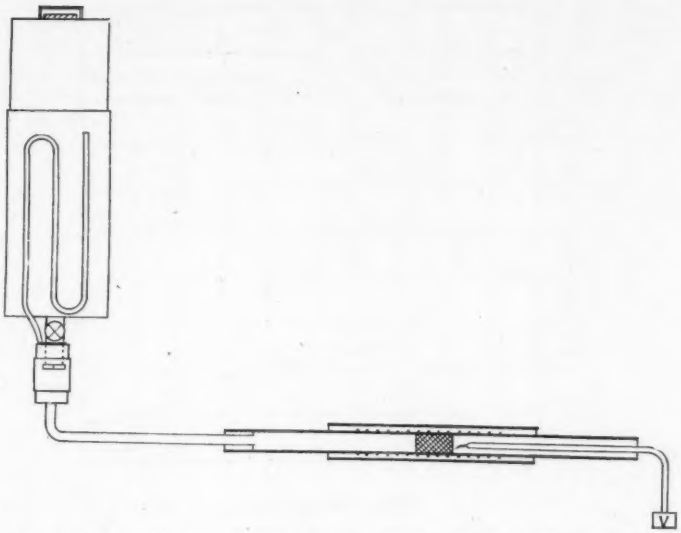

FIG. 1—APPARATUS DESIGNED BY AUTHORS FOR DETERMINING EFFECT OF HEAT ON PERMEABILITY OF MOLDING SANDS.

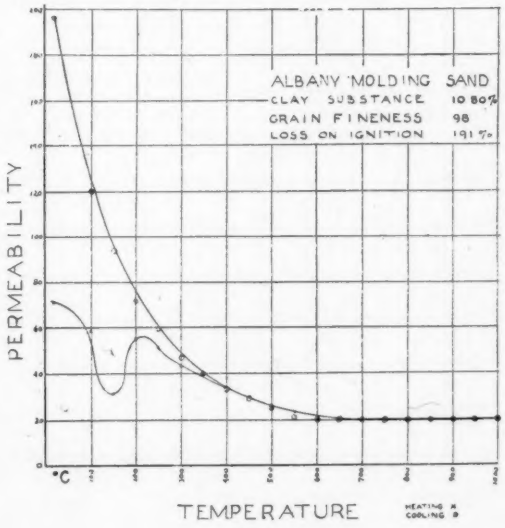

FIG. 2

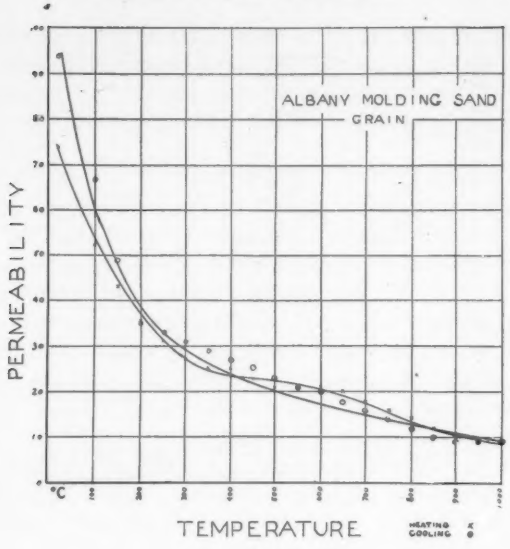
ALBANY MOLDING SAND
GRAIN
PERMEABILITY
°C
TEMPERATURE
HEATING
COOLING

FIG. 3

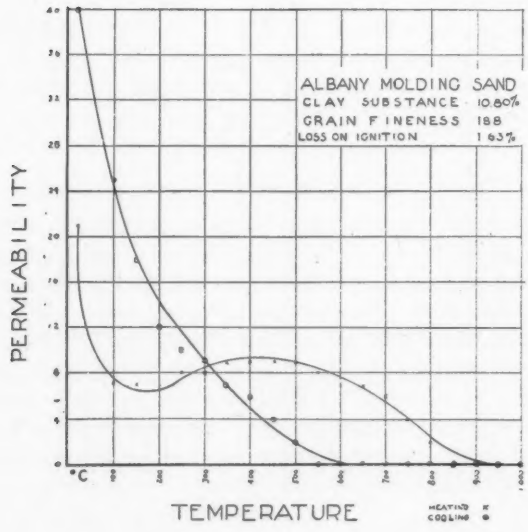
ALBANY MOLDING SAND
CLAY SUBSTANCE 10.80%
GRAIN FINENESS 188
LOSS ON IGNITION 1.63%
PERMEABILITY
°C
TEMPERATURE
HEATING
COOLING

FIG. 4

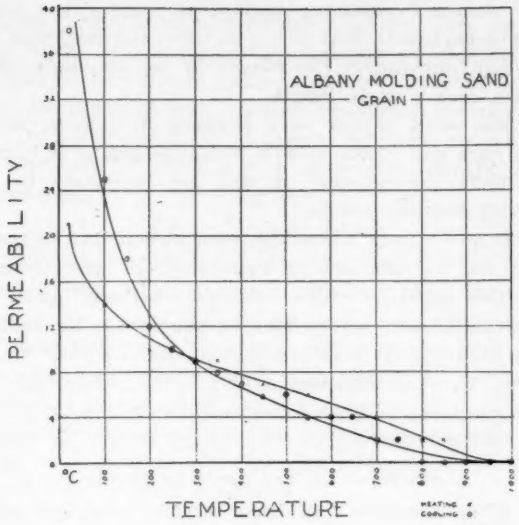
ALBANY MOLDING SAND
GRAIN
PERMEABILITY
°C
TEMPERATURE
HEATING
COOLING

FIG. 5

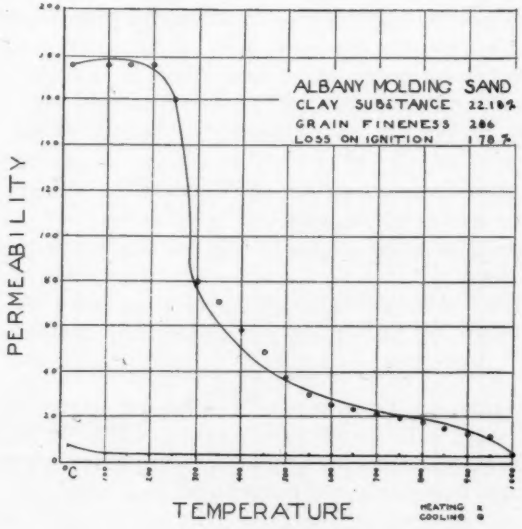
ALBANY MOLDING SAND
CLAY SUBSTANCE 22.18%
GRAIN FINENESS 286
LOSS ON IGNITION 1.78 %
PERMEABILITY
°C
TEMPERATURE
HEATING
COOLING

FIG. 6

A. F. A. standard ramming apparatus. Since the area of a 1-in. tube is one-fourth that of a 2-in. tube, the sand was rammed with a weight one-fourth the weight in the standard apparatus to obtain a core 2 in. in length.

12. The sand grains were rammed dry, using a 12-mesh screen on each end of the core to keep the grains in place. Preliminary tests showed that it was not necessary to use the screens with molding sands.

13. In most tests where the wire screen was rammed with the sand, the 0.5-mm. orifice was found to give permeability readings the same as that obtained without wire screens. Although the 0.5-mm. orifice may be inaccurate for some of the pressures obtained in these tests, the permeability figures are comparable for the different sands. Embedding the thermocouple in the test core was impractical, due to difficulties in ramming. All molding sands were tested with 6 per cent water.

Readings at 50-Degree Intervals

14. After the core had been rammed and the apparatus set up as illustrated, the permeability was obtained at room temperature. The current was turned on and the temperature raised approximately 50 degs. Cent. per ten minutes throughout the test, by using a rheostat. At each 50-degree interval, the

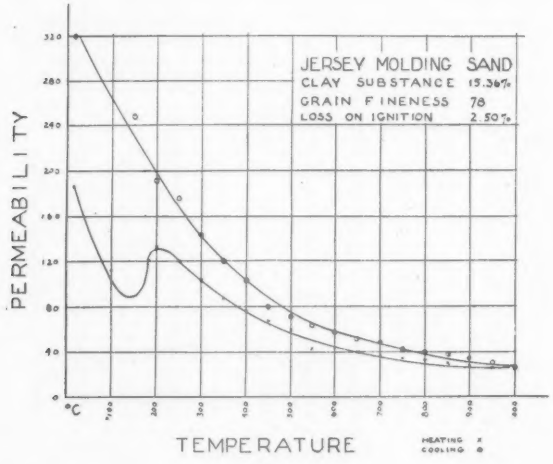

FIG. 7

permeability was determined by opening the cock in the permeability outfit and reading the pressure on the manometer.

15. After the furnace temperature had reached 1000 degs. Cent. the temperature was lowered gradually, readings of the permeability being taken at 50-degree intervals as the furnace cooled. The rate of cooling was somewhat quicker than the rate of heating.

Origin of Sands Tested

16. The sands studied in this investigation were from New York, New Jersey, Ohio, Alabama and Belgium. The grains of the Albany, New York and Millville, N. J., sands were also used, after washing them free from clay, as in the A. F. A. fineness test. All results are plotted with permeability as ordinates and temperature as abscissae. These are shown in Figs. 2-13, inclusive. The grain fineness and clay substance, and the loss on ignition of each sand as determined by the A. F. A. standard tests, are shown on each graph.

Discussion of Results

17. While the figures for permeability are different for each sand, it will be seen from the graphs that the permeability-versus-temperature curves have the same general characteristics. As the temperature of the sand increases, the permeability falls off gradually. At a fairly low temperature around 200 degs. Cent., the permeability is low. Around 300 degs. Cent. it increases, before falling off gradually to a very low figure at 1000 degs. Cent.

18. The curves obtained on cooling are much smoother and show that the permeability increases slowly down to around 600 degs. Cent. From 600 degs. Cent. to room temperature, the increase is quite noticeable.

19. With the grain alone, however, the permeability curves for both heating and cooling are practically the same.

Observations on Gas Reactions

20. When molten metal is poured into the green-sand mold, a thin layer of sand in contact with the metal is heated at once to nearly the temperature of the metal already cooling. The water in this layer is at once turned into steam and superheated. A small amount of gas from the decomposition by the heat of the organic matter of the sand also is given off.

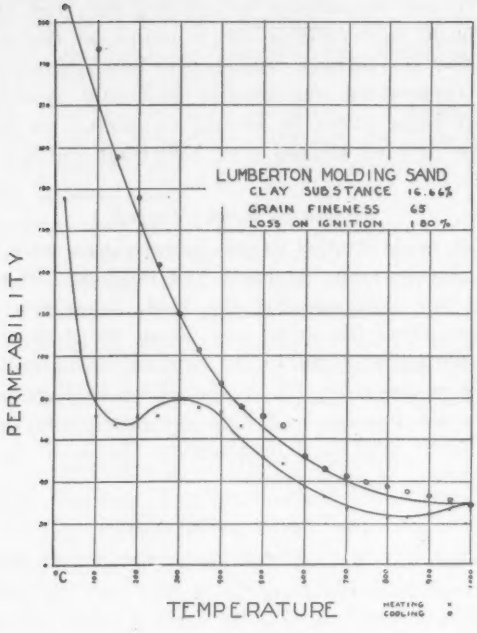
LUMBERTON MOLDING SAND
CLAY SUBSTANCE 16.66%
GRAIN FINENESS 65
LOSS ON IGNITION 1.80%
PERMEABILITY
°C
TEMPERATURE
HEATING ×
COOLING ○

FIG. 8

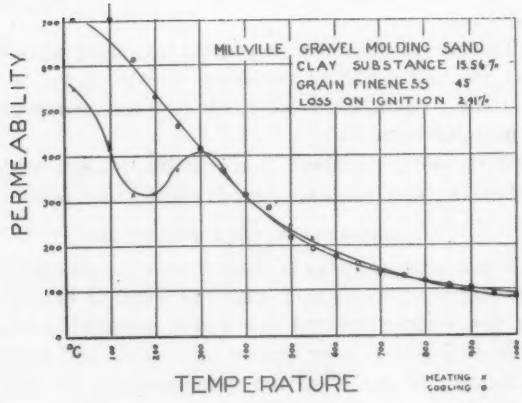
MILLVILLE GRAVEL MOLDING SAND
CLAY SUBSTANCE 13.54%
GRAIN FINENESS 45
LOSS ON IGNITION 2.91%
PERMEABILITY
°C
TEMPERATURE
HEATING ×
COOLING ○

FIG. 9

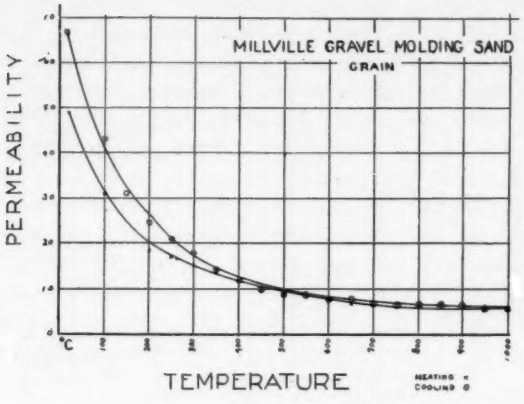
MILLVILLE GRAVEL MOLDING SAND
GRAIN
PERMEABILITY
°C
TEMPERATURE
HEATING ×
COOLING ○

FIG. 10

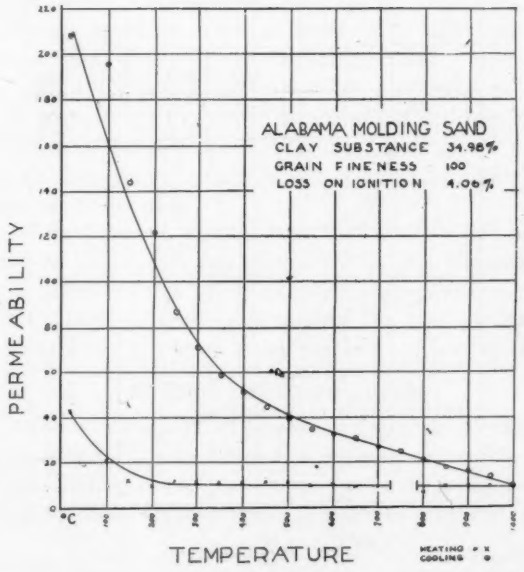
ALABAMA MOLDING SAND
CLAY SUBSTANCE 34.98%
GRAIN FINENESS 100
LOSS ON IGNITION 4.06%
PERMEABILITY
°C
TEMPERATURE
HEATING × ○
COOLING ○

FIG. 11

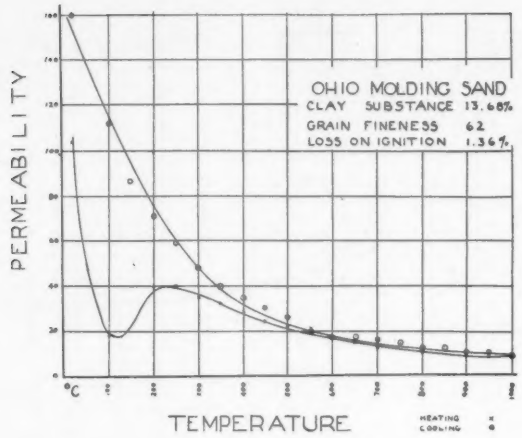
OHIO MOLDING SAND
CLAY SUBSTANCE 13.68%
GRAIN FINENESS 62
LOSS ON IGNITION 1.36%
PERMEABILITY
°C
TEMPERATURE
HEATING ×
COOLING ○

FIG. 12

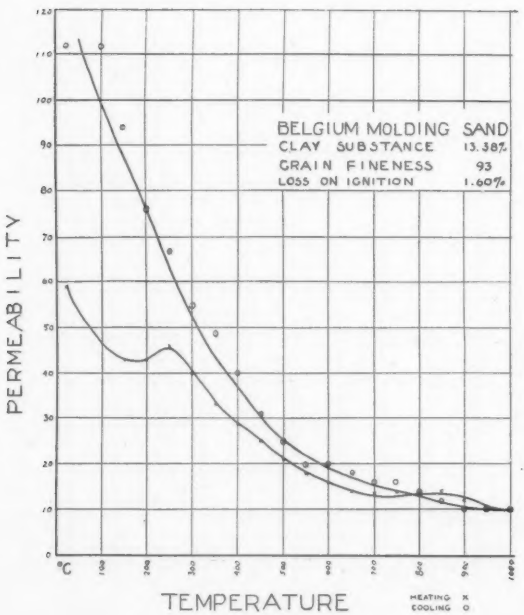
BELGIUM MOLDING SAND
CLAY SUBSTANCE 13.38%
GRAIN FINENESS 93
LOSS ON IGNITION 1.60%
PERMEABILITY
°C
TEMPERATURE
HEATING ×
COOLING ○

FIG. 13

21. In addition, air held within the pores of the sand is expanded. The pressure formed is relieved by the gas passing into or through the next layer of molding sand. In turn, this is heated by the hot gases. There is no flow of gases other than that due to relieving the pressure of the expanding gases.

22. Further heating of the sand is due to conduction of the heat from grain to grain. The heating effect on the mold is well described in a recent investigation,[2] and shows that there are several variables to be considered.

23. The relationship between volume increase of quartz with temperature is also shown. Up to 575 degs. Cent., quartz expands considerably; but from 575 to 1250 degs. Cent. there is practically no increase.

Variations Noted in Permeability

24. On heating sand, therefore, there will be considerable variation in permeability at the temperatures where moisture is given off, namely, between 100 degs. Cent. and 200 degs. Cent. The permeability will also decrease, due to the expansion of the grains, until a temperature of about 600 degs. Cent. is reached. From 600 degs. Cent. to 1000 degs. Cent. there will be little change in permeability, because there is no appreciable expansion of the sand grains to cut down the flow of air.

25. An apparent exception to this statement is shown by the break in permeability curve between 700 and 800 degs. Cent. in the Alabama molding sand (Fig. 11). Around 750 degs. Cent. the permeability varied so much that it was impossible to obtain the same reading twice.

26. It is believed that the water of constitution of the clay substance of this sand was given off at this temperature and created a situation similar to what happens between 100 degs. Cent. and 200 degs. Cent. As shown, the loss on ignition for this sand was 4.06 per cent, much higher than any of the others.

Heating and Cooling Data

27. The removal of moisture and drying of the clay by heating is probably responsible for the uniform curves obtained on cooling molding sand. The curves for heating and cooling the grain of a molding sand (Figs. 3, 5 and 10) confirm this belief,

[2] A. H. Dierker, *Reclaiming Steel Foundry Sands*. Technical Publication No. 261, December, 1929, American Institute of Mining and Metallurgical Engineers.

since no moisture was used in ramming the sand-grain core.

28. Due to the uniform slope of the curves obtained on cooling the sand cores, it is believed that channeling did not take place. In Fig. 6, however, it is possible that there was channeling, since the permeability remains the same between 200 degs. Cent. and room temperature. This sand contained an unusual amount of clay and was extremely fine.

DISCUSSION

ORAL DISCUSSION

DR. H. RIES:* Does the loss on ignition which has been referred to involve the total loss up to 1000 degs Cent., and if so, does it include the loss at 100 degs. Cent.?

W. M. SAUNDERS, SR.: The loss on ignition was determined by the A. F. A. standard test. The sand was dried at 105 degs Cent., one gram was ignited for some time to constant weight and the loss was called "loss on ignition."

DR. H. RIES: I wish, in some future test where there is an appreciable loss on ignition, that you could get that loss at several temperatures. It might mean something. Dehydration may take place at different temperatures.

W. W. KERLIN:† In regard to dehydration at various temperatures, I did considerable work on that some years ago, and I found that it is just as Dr. Ries says. Certain clays dehydrate at lower temperatures and others at higher. I investigated several bonding clays and I found that, in general, they lose about 70 per cent of their combined water at about 650 degrees; after the temperature of 650 degrees, the rate was somewhat lower. Finally, around 1,000 degrees it was completed.

Also, in regard to dehydration of bond and to the composition of bond, when you consider bond from the colloidal standpoint, when you wash out the bond and allow it to settle in a 12-quart volume for about half a hour and then siphon off and allow it to settle, you have a clay which approaches more nearly the colloidal state than you do in a regular A. F. A. test.

In all the clays that I have tested, the more colloidal the clay is, the more nearly it approaches the composition of kaolin, although I never had one exactly reach the kaolin composition. The closest I ever got was one which contained about 13 per cent combined water against 15 per cent for the pure compound. That was the basis for my opinion that probably the ideal mixture for pure clay bond was kaolin.

On some work I did on fire clay, I separated the bond and the residue, as I stated before, and the residue contained more silica than

*Cornell University, Ithaca, N. Y.
†Enterprise Sand Co., Pittsburgh.

the colloidal bond. In other words, as the bond was removed from the fire clay and from the bonding clay as well, the residue got farther away from the ideal composition of kaolin, whereas the actual bond itself approached it. This observation does not hold in the case of bentonite, however.

MEMBER: I would like to ask if the speaker knows how those diagrams might apply to any rebonding material that might be put into sand—such as bentonite, loose lignite or any of those bonding materials —and how that might affect the hot permeability of the sand.

W. M. SAUNDERS, SR.: I do not believe this is a very practical paper. It is a record of what happens when the molding sand is heated, as to affect on the permeability. The effect of heat on bentonite is another study.

CHAIRMAN O. E. J. ABRAHAMSON:* I might answer the speaker by stating that the permeability relationship of a sand, regardless of whether it is a natural sand or a molding sand as manufactured using bonding materials, should be practically the same under the same conditions as Mr. Saunders experimented with. I do not see why it should make much difference whether you use bentonite or natural bonds such as occur in natural molding sands.

MEMBER: I understand that in the course of these experiments Mr. Saunders raised the temperature by steps. Is that so?

W. M. SAUNDERS: Not exactly by steps. Temperatures were constantly increasing. The heat was not shut off at all, and every fifty degrees we would take readings which were of ten minute intervals.

MEMBER: Then you have made no study of the effect of different rates of heating, or did you keep that at a standard?

W. M. SAUNDERS: It was assumed that ten minutes would heat the core through. In fact, less time than that will do it.

R. F. HARRINGTON:** It seems to me that Mr. Saunders has struck a very important point. At one temperature, very low relatively, we note the drop in permeability. It seems to me we have there the answer to the question of permeability on dry-sand molds. In the dry-sand mold we do not have that steam pressure to work against.

While Mr. Saunders considers his paper rather theoretical or academic, it gives us an answer to the fact that our dry-sand molds offer less resistance to the gases than do the green-sand molds.

W. M. SAUNDERS: A practical application, possibly, would be in the preparation of the mold for pearlitic iron.

A. C. JONES:† Mr. Saunders is to be complimented on his piece of fundamental work, although Mr. Harrington has a practical application immediately. So many things influence the permeability of a green-sand mold, particularly, that each condition has to be considered separately.

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*Buffalo.

**Hunt-Spiller Manufacturing Corporation, Boston.

†Lebanon Steel Foundry, Lebanon, Pa.

For instance, the moisture content, the nature of the sand, and probably a number of other things must be considered. However, I think many of you are as surprised as I was to find that the permeability drops so low after reaching some of those higher temperatures. As Mr. Saunders explained, it is due to the expansion of sand grains but the intensity of that expansion was not realized until Mr. Saunders' experiments.

Core Room Conveyors

By D. B. Hill,* Detroit

Abstract

Production requirements in modern foundries demanded more economical methods of baking and handling cores than were possible under conditions existing a few years ago. Continuous baking ovens, supplemented by conveyors for transporting the cores in process, were developed. Early types of these mechanical installations had certain objections which were overcome by later designs. Conservation of heat, saving in floor space and cost of handling were three main items considered. Horizontal types of installations were found to be, as a rule, more advantageous than the vertical type. Various installations are described.

Early Method of Handling

1. The economical transportation of cores has been a source of great expense and the subject of much study.

2. An early type of core oven was a large box or room heated to a baking temperature. The cores were placed in racks and were transported to and from the ovens by means of lift trucks. The objections to this method included:

Breakage of cores.
Investment for trucks and truck maintenance.
Large number of racks and the amount of floor space and labor required.

3. One of the first noted improvements over the above method was the substitution of I-beam monorail and trolleys for lift trucks. The core racks, suspended from trolleys, were transported to and from the ovens and the monorail served as a storage and cooling space.

Meeting Increased Production

4. The advent of mass production in all branches of industry—especially noticeable in the manufacture of automobiles

*Manager, Foundry Division, Palmer-Bee Co.

—made large production foundries necessary. Soon engineers were faced with the problem of increased core-room capacity. The continuous movement of cores through the operations of making, baking, cooling, pasting and delivery to molders was suggested by progressive foundry and conveyor engineers. This method would be in keeping with the continuous transportation of molds already adopted.

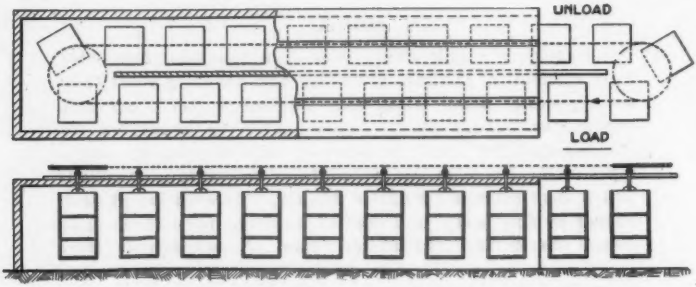

FIG. 1—ONE OF EARLIEST TYPES OF POWERED CONTINUOUS CORE-OVEN CONVEYORS. OVEN WAS OF BRICK WITH SLOTS IN ROOF FOR OPERATION OF TROLLEY SYSTEM. THESE SLOTS, RESULTING IN GREAT HEAT LOSSES AND OTHER OBJECTIONS, CAUSED REDESIGNING. *(See Fig. 2)*

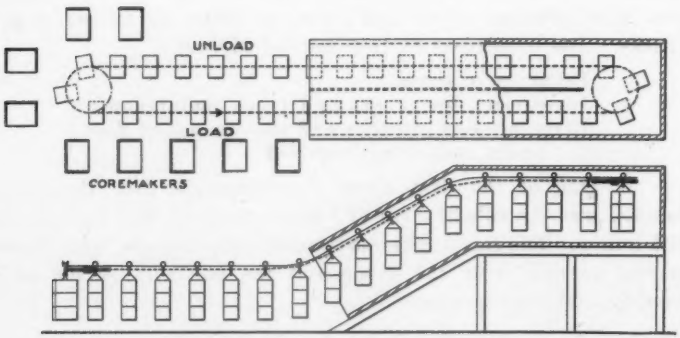

FIG. 2—HORIZONTAL-TYPE OVEN DESIGNED TO OVERCOME SOME DEFICIENCIES OF OVEN IN FIG. 1. LENGTH OF CONVEYOR OUTSIDE THE OVEN INCLUDED COOLING PERIOD AND UNLOADING SPACE. HEAT LOSSES DUE TO ROOF SLOTS WERE ELIMINATED BY PLACING CONVEYOR IN THE OVEN PROPER. *(See Fig. 3)*

5. The wisdom of using conveyors for this purpose was questioned by many. It was thought that vibration would break the green cores before they could be baked. The investment for continuous core ovens and conveyors seemed to be out of proportion to the work accomplished. The protection of the conveyor chain and mechanism from the oven heat presented a difficult problem.

AN EARLY TYPE

6. The earliest type of power-driven continuous core-oven conveyor, shown in Fig. 1, was successful enough to justify the idea that cores could be baked by a continuous process. This type of oven was of brick and employed two sprockets with a conveyor chain placed above the oven. Slots through the roof of the oven permitted the suspension member connecting the trolley to the core rack to follow the travel of the chain.

7. Objections found in this design were:

(1) Enormous heat loss due to slots in the roof of the oven and the lack of heat seals at the entrance and exit.

(2) Oven occupied useful floor space.

(3) Loading and unloading spaces limited.

(4) Insufficient cooling time.

(5) Transporting green cores due to inability to group core makers adjacent to loading point.

8. The design which was offered to overcome some of these objections is shown in Fig. 2.

HORIZONTAL OVENS

9. The first oven of the horizontal type occupied a comparatively small floor space, due to the type of cores produced. It was designed for cores requiring a short baking time. By making the length of the conveyor outside of the oven of sufficient length to include cooling period and unloading space, together with the space around which the core makers were grouped, the objections found in the oven shown in Fig. 1 were overcome.

10. The inclination of the entrance and exit of the oven formed the heat seals. This construction required the use of sheet-metal ovens instead of brick. Placing the conveyor in the oven eliminated the slots in the roof and reduced heat losses to a minimum.

11. In order to meet the conditions imposed by this design, the conveyor engineers were confronted with the designing of a chain which would operate in both the horizontal and vertical planes. This resulted in the type of chain and trolley shown in Fig. 3.

12. The 6-in. diameter wheels of the trolley operate over double-angle tracks and are fitted with anti-friction bearings. The trolley stem is suspended from a high-carbon steel shaft and supports the core rack in such a position that the shelves always remain in a horizontal plane. A transverse joint provided at the junction of the chain and trolley stem permits the chain to travel up and down inclines as well as on horizontal tracks.

13. The rollers in the chain joints provide for operation around roller turn and traction wheels, and make action on the drive sprocket easier. Trolleys equipped with anti-friction bearings can convey loads of a ton per rack with little power.

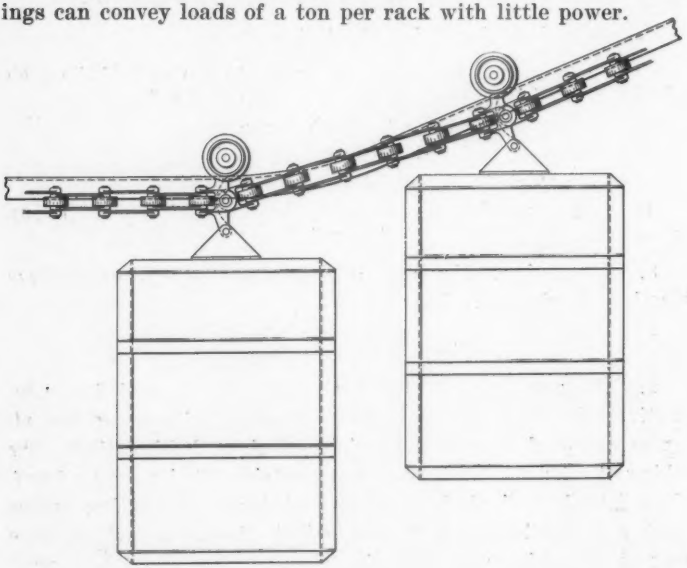

FIG. 3—CHAIN AND TROLLEY UNIT MADE NECESSARY BY DEVELOPMENT OF OVEN SHOWN IN FIG. 2, AND DESIGNED TO OPERATE BOTH HORIZONTALLY AND VERTICALLY BY MEANS OF TRANSVERSE JOINT. ANTI-FRICTION BEARINGS ON TROLLEYS PERMIT HANDLING OF LOADS OF A TON PER RACK WITH MINIMUM OF POWER.

14. The largest oven of the horizontal type of which we have a record has 150 racks with a gross load of one ton each, and requires a 5-horsepower motor to drive the conveyor. An example of an oven of the larger type is shown in Fig. 4.

15. This oven is designed to serve bench core makers. A conveyor passes between the two rows of benches. The core makers face the approaching conveyor and rack, permitting the makers to select a location to place their cores. A half turn of the body and a step is the only movement required to load the rack.

16. The conveyor track is inclined so that the lower shelves of the rack are loaded as easily as the upper. With this load the rack travels up an inclined track of 20 degrees into the oven proper, traversing its length three times on level track fitted with expansion joints.

17. The chain leaves the oven over an incline, converging into a horizontal track before reaching the drive sprocket. The contraction and expansion of the chain is compensated by the

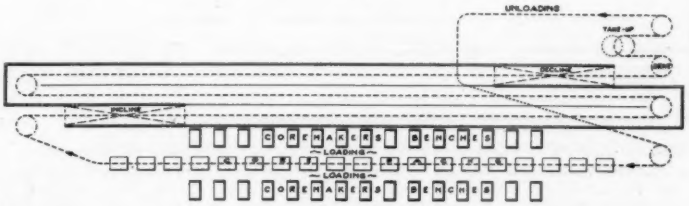

FIG. 4—LAYOUT OF LARGE TYPE HORIZONTAL OVEN, DESIGNED TO SERVE BENCH CORE MAKERS. CONVEYOR PASSES BETWEEN TWO ROWS OF BENCHES, FACILITATING LOADING OF RACK. RACK TRAVELS INTO OVEN ON TRACK FITTED WITH EXPANSION JOINTS, AND TRAVERSES OWN LENGTH THREE TIMES. CHAIN IS COMPENSATED FOR EXPANSION AND CONTRACTION BY MOVEMENT OF A COUNTERWEIGHTED TAKEUP CARRIAGE.

movement of the counterweighted takeup carriage. This mechanism is located adjacent to the drive sprocket.

18. From the takeup the conveyor passes around a roller turn to a portion of straight track where the racks are unloaded onto filing, sorting and fitting benches. From this point the empty racks pass underneath the oven to the original starting point. Sprocket and traction wheels are all mounted on antifriction bearings.

MEETING PRESENT DAY REQUIREMENTS

19. In order for a continuous conveyor oven to be successful, the following conditions must be met:

(1) Adequate and accessible loading space.
(2) Ample baking time.
(3) Sufficient time and apparatus for cooling.
(4) Well-located unloading position.
(5) Produce cores economically.

20. An oven which illustrates all of these features is shown in Fig. 5.

21. This conveyor makes four passes through the length of the oven. As the conveyor leaves the oven it passes through an enclosed cooling chamber. This chamber completely surrounds the drive and takeup mechanism, and is supplied with the necessary fans for directing a blast of air on the cores.

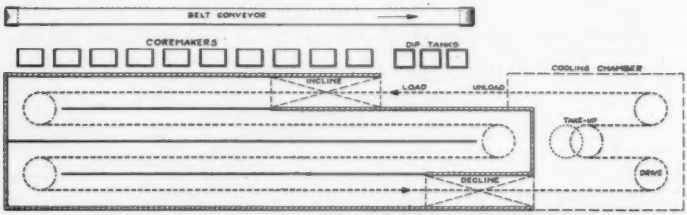

FIG. 5—MODERN CONTINUOUS-CONVEYOR OVEN PRODUCING CORES ECONOMICALLY BY MEETING REQUIREMENTS AS TO BAKING TIME, LOADING AND UNLOADING SPACE AND POSITION, AND TIME AND APPARATUS FOR COOLING. AFTER FOUR PASSES THROUGH LENGTH OF OVEN, CONVEYOR PASSES THROUGH ENCLOSED COOLING CHAMBER PROVIDED WITH AIR FANS. UNIT WAS DESIGNED TO BAKE 480 CRANK-CASE CORES PER HOUR.

The cores are cooled to a temperature so that they can be unloaded with the bare hands.

22. Cores, together with their plates, are placed on to a gravity conveyor underneath and extending the length of the oven. Cores are unloaded, classified and stored on racks or transported to the foundry. The plates are returned to the makers' benches from the gravity conveyor. The makers' benches are located adjacent to the oven.

23. A belt conveyor is situated directly behind the makers and transports the cores through a distance of approximately 100 feet parallel to the oven. Cores are removed from the belt conveyor, dipped into a blackening tank and loaded onto the

conveyor racks at a point prior to entering the oven. This unit was designed to bake 480 crank-case cores per hour.

ADVANTAGES OF THE HORIZONTAL-TYPE CONTINUOUS-CONVEYOR CORE OVEN

(1) Saving in Floor Space.

24. It is shown that the space underneath the oven may be used for core or rack storage, sorting, filing, fitting, blacking, pasting or inspecting cores, etc. The ovens in many cases are supported above roof trusses, keeping the floor clear of supporting columns. Installations have been made where the oven extends over an areaway between buildings.

(2) Labor Saving.

25. With the conveyor located adjacent to core makers' benches, the time spent in walking to and from distant racks is eliminated. The labor used in transporting racks from the makers to the oven is entirely dispensed with.

26. In the process of loading rack-type ovens it is often necessary to move the rack several times before it is placed in the oven. One large automobile firm had a piece rate of 1¾ cents for each movement of racks. This item alone amounted to thousands of dollars per year.

(3) Reduced Core Breakage.

27. Handling cores on racks with trucks resulted in a large loss due to rough floors, collision with other objects, etc. With the smooth operation of the oven conveyor, this breakage is negligible.

(4) Pace Setter.

28. As the racks travel in full view of the operator, this enables him to time his movements with the speed of the conveyor.

(5) Uniformity of Product.

29. With each rack load of cores receiving the same baking and cooling time, the product will become uniform. This eliminates the human element which enters into the loading and unloading of rack-type ovens.

(6) Working Conditions.

30. Heat is confined in the sheet-metal oven with insulated walls and heat seals. With this construction a comfortable tem-

perature can be maintained in the core room. This condition could not be enjoyed where rack-type oven doors are opened for loading and unloading.

(7) Reduction of Equipment.

31. With the conveyor returning racks, core plates and dryers at regular intervals, the amount of this equipment is materially reduced. The increased production per man decreases the number of core machines required.

VERTICAL OVENS

32. Due to architectural limitations of present core rooms, nature of the product and other limitations, the vertical-type oven has met with the approval of a large number of plant owners and operators.

33. The vertical oven is used to advantage for:

(1) Baking small cores.

(2) Drying cores after blacking.

(3) Drying cores after pasting.

34. The limitations of the vertical oven for baking cores are based on the requirements noted under the heading "Meeting Present Day Requirements" (paragraphs 19-23, inclusive).

35. If the production is very large, it is often difficult to place the core makers in accessible position for loading directly onto the core racks. To overcome this the core makers are grouped parallel to a belt conveyor which serves to deliver the cores from the makers to the oven. The belt conveyor is usually constructed as a gravity carrier, with idler rolls on the carrying side to prevent undue sagging and resultant vibration in the belt.

36. As the cores reach the oven, an operator is required to unload the belt and place the cores onto the racks. The cores are usually unloaded on the opposite side, the plates remaining on the racks, and are unloaded by the loading operator. These plates are distributed to the core makers by a section of gravity extending the length of the bench layout.

37. A view of two ovens utilized in this manner is shown in Fig. 6.

38. An unusual takeup mechanism is used in this design. It consists of a frame in the form of an "U" fitted with counterweights, if necessary, and eliminates the necessity of shaft and sprockets at this point. It meets the requirements of the ex-

pansion and contraction of the chain and also provides for loading between the vertical strands of the conveyor. The space between the vertical runs of the conveyor can be floored over, giving easy accessibility to the core makers.

39. The vertical oven is recommended for baking small cores only, because it is practically impossible to extend a vertical oven of this type sufficiently high to incorporate the required amount of cooling time and apparatus for large cores.

40. A very unique design employing the vertical oven, together with a conveyor, and which serves the core makers, provides ample cooling time, unloading space and return of plates and dryers to the operators, is shown in Fig. 7.

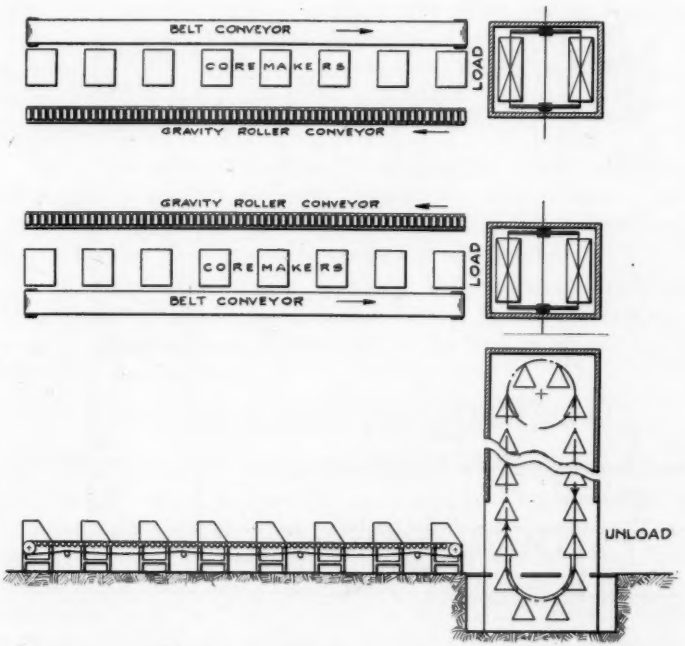

FIG. 6—TWO OVENS EQUIPPED FOR LARGE PRODUCTION, WITH CORE MAKERS GROUPED PARALLEL TO BELT CONVEYOR, WHICH DELIVERS CORES TO A POINT WHERE THEY ARE UNLOADED AND RELOADED ONTO RACK BEFORE ENTERING OVEN. WHEN CORES ARE UNLOADED AFTER LEAVING OVEN, THE PLATES REMAIN ON RACKS FOR DISTRIBUTION TO CORE MAKERS BY GRAVITY SECTION WHICH EXTENDS THE LENGTH OF BENCH LAYOUT.

41. The operators on this installation are all girls. They are placed on a mezzanine floor and segregated from the male employees. The core room is fully enclosed. Proper lighting and ventilation is provided, making this department ideal for this type of work.

42. The benches are located adjacent to the upper run of the conveyor. The conveyor is inclined so that the top and bottom shelves are loaded without undue exertion on the part of the operators. The conveyor passes through the vertical runs of the oven. On the descending side, the cooling fans are placed so that the cores are sufficiently cooled to be unloaded with the bare hands.

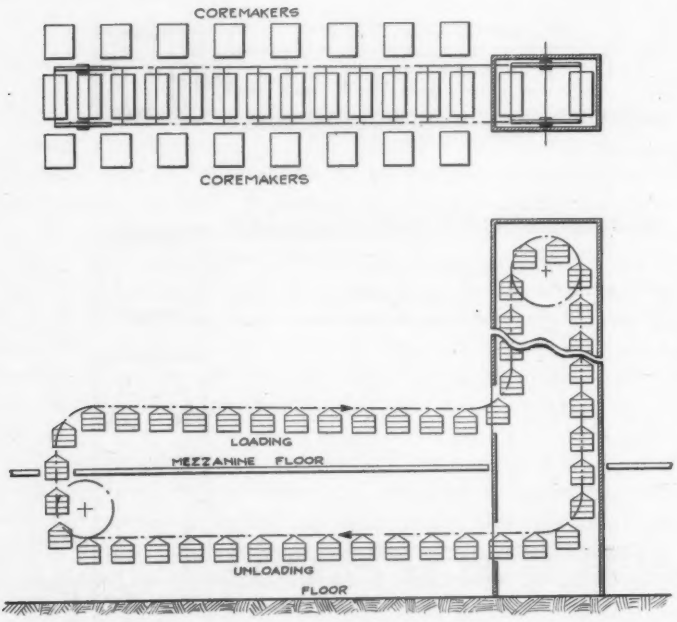

FIG. 7—UNIQUE DESIGN OF VERTICAL OVEN ADAPTABLE EQUALLY WELL TO LARGE OR SMALL CORES. PROVIDES FOR AMPLE COOLING TIME, UNLOADING SPACE AND RETURN OF PLATES AND DRYERS TO OPERATORS (ALL GIRLS, IN THIS INSTALLATION), WHO ARE LOCATED ON A MEZZANINE. INCLINED CONVEYOR PERMITS EASY LOADING OF BOTH TOP AND BOTTOM SHELVES. ON LEAVING OVEN, CORES ARE COOLED BY FANS SO THAT THEY CAN BE UNLOADED WITH THE BARE HANDS.

43. Cores are sorted into tote-boxes placed on gravity conveyors. These conveyors may be placed in suitable locations on either side of the lower horizontal run of the oven conveyor. The plates and dryers are placed on racks and are returned through the floor to the operators on the mezzanine floor.

44. This type of installation provides for every requirement necessary for the successful operation of a continuous type conveyor oven. The conveyor used in this and other vertical installations consists of two parallel strands of steel-bar bushed roller chain.

45. The rollers are unusually large in diameter, fitted with bronze bushings and provided with a large oil reservoir eliminating the possibility of the conveyor operating without lubrication. The parallel strands of chain are connected by means of cross rods over which extra-heavy pipe is placed. The pipe provides for additional stiffness, and due to the fact that it is easily replaced in case of wear, it has proven an added feature in this design.

46. The racks are suspended from these cross rods by U-bolts, which provide for easy installation and removal. The absence of sprockets on the mezzanine floor is an additional safety feature which we have evolved in this design.

47. This design may be employed with excellent results for large cores as well as small ones. This is due to the fact that a cooling chamber can be included in the horizontal run up to the point of unloading.

PASTING, DRYING AND BLACKING OVENS

48. The ovens required for this class of work usually are very small, due to the speed of the conveyor. Twenty to thirty minutes cover the usual time required for these operations. These units are usually of such a height that they may be moved from one location to another in the foundry, as the occasion demands. This advantage has been valuable in several instances of rapid expansion in different plants.

OTHER TYPES OF CONVEYORS

49. We have covered the core-oven conveyor but feel that this paper would not be complete without mentioning other

types. Gravity carriers, properly designed belt conveyors and other types may be used to advantage.

50. The overhead monorail system of distributing sand to core makers has met with the general approval of everyone concerned. Usually one operator with an electrically-operated machine can distribute the sand required for fifty to sixty core makers. This equipment is usually supported from the roof trusses, leaving the floor free of any additional supporting columns.

DISCUSSION

ORAL DISCUSSION

A. C. JONES:* Mr. Hill, considering only the baking cost of the cores—moderately sized cores—what would be the advantage of a continuous horizontal-type oven as against the former box-type oven? Is it possible, with such a continuous oven, to use waste heat from some other continuous heat-treating operation so as to make it worth one's while? I want to get an approximate idea of the saving in the baking phase only with the continuous oven as compared with a batch oven, with the same type of cores.

D. B. HILL: I am going to ask Mr. Fox, who has had much more experience in oven design and in heating and ventilation than I have, to answer these questions.

V. A. FOX:† That is pretty hard to answer definitely without knowing the specific weight of cores you make, or the kind you make. Usually, in any continuous baking oven, vertical or horizontal, the baking time can be reduced, because a better baking condition is obtained in the oven. We usually are able also to reduce the fuel cost over that of a box-type oven.

As to your second question, heat from some other source—if it is in large enough volume and at such temperature that it can be handled or can be put into the core ovens—can be used.

A. C. JONES: Some people say that waste heat from some other continuous heat-treating operation cannot be used efficiently.

V. A. FOX: Remote heaters are being used for continuous ovens in foundries and in a good many other industries, and if a remote heater can be used, certainly that other source of heat for the oven is approximately as intense as a remote heater. I would say it could be used if desired, and at temperatures that can be introduced into the oven without burning the cores.

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*Lebanon Steel Foundry, Lebanon, Pa.

†Young Brothers Co., Detroit.

C. A. BARNETT:* Answering Mr. Jones' question from our specific experience, the question as to whether or not fuel can be saved in the continuous-type oven over a rack-type oven presumes, of course, that the same sort of work is being handled.

We have an instance where we have taken a certain production—formerly baked in rack-type ovens but now baked in continuous ovens of the vertical type—and the fuel consumption has been reduced fully one-third. However, that is not the entire story. The cores were formerly baked in inefficient, crude, home-built ovens, and the efficiency of those ovens might easily have been increased 25 per cent. The difference, therefore, is not entirely due to the mechanical-type equipment.

It should be kept in mind, in connection with the fuel economy of continuous ovens, that the very nature of the racks requires certain clearances between them in moving about the sprockets, and clearance above the trolleys, hangers and tracks, etc. There is, therefore, a certain amount of dead space in a continuous oven, which penalizes to some extent what would normally be the efficiency of the continuous operation.

We have built several large conveyor-oven installations which have produced rather low fuel ratios. On the other hand, we have been able, on batch-type installations, to obtain as low fuel ratios as the very best of the continuous installations.

The best opportunity to save fuel in a continuous oven lies in operating the oven loaded to full capacity. If the production is apt to vary, the fuel economy on a continuous oven is severely penalized when the oven is running under capacity, and a comparison with batch-type oven operation may favor the latter.

With regard to the use of waste heat, as Mr. Fox has said, this depends upon how much is available, what its temperature is and how far the source of this waste heat is from where it is to be used.

A number of years ago we were called in to figure on the installation of a battery of core ovens where the owner wished to use the waste heat from his cupola. The cupola was on an upper floor. The owner had already designed and built his own fan to take the waste heat from this cupola, and to deliver this heat through large ducts to the ovens, which were to be located on the floor below. The fan was of such huge size and the blades of such terrific weight, that the actual power consumption of the motor to drive the fan would have cost a great deal more than new fuel to run the ovens.

The coordination of the equipment producing this waste heat and the operation of the ovens is another point which should be kept in mind.

This brings to mind an experience of 14 or 15 years ago at one of the automotive plants, where we were to take the waste heat from a large battery of pit-type brass-melting furnaces to heat a group of core ovens. The furnace operated all right so long as nothing interfered with the flow of the heat in the runner flue or waste-heat duct, but as soon as the velocity of these gases was reduced by passing them through the ovens, the normal operation of the furnaces was seriously affected.

*Foundry Equipment Co., Cleveland.

Using waste heat from annealing furnaces or heat-treating furnaces can be done in a number of ways. A recuperator can be used to preheat air by means of the waste heat being discharged from the furnace, and this preheated air could become a very good heating medium for a core oven, because all the elements of good economical operation are available. You have convected heat in a desirable oxidizing condition, and if there is available a sufficient volume and a constant supply, the desired result could be practicably accomplished.

If one of the elements is missing—for example, if there is not available a constant supply—auxiliary heating equipment can be installed, automatically controlled, to cut in and out as the waste-heat supply varies.

The source of waste heat should be reasonably close to where it is to be used, so as to reduce to a minimum the investment in duct work, which must be well constructed and heavily insulated.

It may interest many to know that continuous-conveyor core ovens are not as new as some of us seem to believe. The first used continuous ovens I know of are now nearly thirty years old. They are vertical conveyor ovens or brick-type construction and are still in daily operation. To the best of my knowledge, practically nothing has been spent for maintenance on these ovens in all this time, outside of the maintenance of the heating equipment.

In connection with vertical-type ovens, Mr. Hill might have touched a little more on the arrangement of the passageway through the oven, which permits a grouping of the core makers around three sides of the ovens.

I have in mind an installation consisting of a number of vertical ovens. One of these ovens has a group of four core-blowing machines along the rear of the oven, three rollover machines at one side and three or four bench core makers on the other side. The men operating the core-blowing machines serve the oven from the rear, the rollover men from one side through the passageway that Mr. Hill has described, and the bench core makers from the other side. One boy takes care of all of the unloading of this entire production.

As the work comes from the vertical ovens, it is placed on boards similar to bottom boards, or in little wooden tote boxes if there is no finishing operation. As the work accumulates on these boards or in the boxes, the cores are shoved along a roller conveyor, where the work is blacked or dipped, as the case may be; and, by the time the work reaches the end of the roller-conveyor run, it is all accumulated and segregated, ready to go to the molders. The interesting thing about this installation is its compactness, the large amount of work that it handles, and its mechanical simplicity.

WRITTEN DISCUSSION

E. W. BEACH:* Mr. Hill's paper has presented the matter of chain propulsion for core-oven racks so concisely that he leaves very little

*Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

room for discussion and, so far as I can see, none at all for argument. Therefore I wish only to add a few facts which have come to me in the operation of installations furnished by Mr. Hill's firm and installed in Young Brothers' ovens.

Our problem in increasing production at the Campbell, Wyant & Cannon Foundry Co. was to adopt the most desirable and economical type of core oven for producing 500 sectional automobile-cylinder crankcase cores per hour. For the past eight years we have used the rack-type oven and two semi-continuous rack-type car ovens operated on the basis of the intermittent rack-type oven. The day's production of cores was baked during the night shift.

The average core weight of these crankcase cores was 88 lbs. each, of several but similar sizes. The cores were baked four hours at a temperature of 400 to 450 degs. Fahr., and the average production per core maker for this type of core was approximately 15 per hour. Therefore, from 32 to 35 core makers were required in order to produce 500 cores per hour.

The vital factors involved were floor space for production and service to the ovens. Several arrangements of vertical and horizontal-type ovens were considered, and our final choice of type and design was the horizontal continuous type, for the same reasons given in paragraph 19 of Mr. Hill's paper.

In Fig. 5 of Mr. Hill's paper the oven we contracted for is illustrated. Its length is 198 ft., width 20 ft. and it clears the roof trusses, which are 18 ft. above the floor, by 4 inches.

This oven has four passes, requiring the core to traverse the length of the oven four times before it arrives at the unloading point. The entire oven, with the exception of the loading and unloading stations and the cooling chamber, is raised above the floor, allowing the use of 80 per cent of the space directly underneath for inspection, sorting, distribution and storage—if needed.

In order to obtain the same production in vertical-type ovens, it was found that we would need a battery of 13. The necessary minimum vertical clearance would be 54 ft., and each oven would take up a 10x10 ft. floor area. This would have necessitated the erection of pent-houses to contain the superstructure of the oven-driving mechanism and also a serious modification of our roof trusses, whereas the horizontal oven was installed without any alterations to the structure. Incidentally, shallow pits usually are necessary in vertical-oven construction.

In either case, the green cores were to be placed on a belt conveyor. On removal from the belt conveyor the cores were to be dipped in blacking tanks and then loaded onto the core-oven conveyor racks. At the finish of the cycle after removing the cores from the racks, the plates were to be returned to the core makers on gravity rollers.

The actual floor space taken up by the horizontal oven, including the core makers' benches and conveyors, amounts to 3,000 sq. ft. The vertical ovens would take approximately 4,000 sq. ft.

Comparing the initial cost, we found that 13 vertical ovens would cost nearly twice as much as one horizontal oven.

Two dip tanks are required with the horizontal type, whereas 13 (or at least 8, if ovens were grouped in pairs) would be needed in the other case. Fewer men would be required for the operation, handling and disposition of cores for the horizontal oven.

The machinery on the horizontal oven is located over the cooling chamber. For the vertical oven, the machinery is usually situated on top, which is the hottest portion of the oven. In the horizontal type, the cores are cooled to the point where they can be conveniently handled with the bare hands at the unloading station of the horizontal oven, unless, of course, one tries to double the guaranteed baking speed.

A 5-h. p. motor is sufficient for the horizontal oven, whereas a 3-h. p. motor is required for each vertical oven, or a total of 39 h. p. for the 13 ovens. A more desirable load factor is obtained in the first case.

In conclusion, our reasons for adopting the horizontal oven are as follows.

(1) Lower initial cost.
(2) Less floor space.
(3) Lower operating labor expense.
(4) Better concentratiton of producing labor favorable to the distribution of material and equipment.
(5) Cooler cores.
(6) No building changes.
(7) Better load factor.

We installed another horizontal oven for crankcase slab cores, which requires a dryer for each core. Previously, a dryer was necessary for each core made per day, inasmuch as all the baking was done at one time. With the present arrangement, our dryer turnover is two and one-half per day, a very considerable item in the initial cost of equipment for a new job.

Profitable Reclamation of Sand in Steel Foundries

By M. D. Pugh,* Chicago

Abstract

In steel foundries not using reclaiming methods, the average consumption of sand is about 1,500 lbs. of new sand for each ton of castings produced. This loss is mainly due to the effect of the high temperature of metal poured into the molds, which breaks up the silica grains, fuses some particles and destroys the active bonding material. Two ways of reducing sand consumption are by reclamation and conservation. Reasons why sands "burn in" are stated to be: Lack of uniformity of sand grains, amount and distribution of clay bond and the quality of the clay, amount of water used, and temperature of the steel when cast. Of these, the most important is uniformity and size of grain. Details of a study of grain size are given. Two main reasons for failures at reclamation are said to be lack of proper attention to condition of sand when it goes to reclaiming unit, and lack of equipment suited to efficient removal of detrimental materials. Green-sand molds must have a higher permeability than dry-sand molds.

1. According to available information, the average consumption of sand in steel foundries in the United States without any form of reclaiming system is about 1500 lbs. of new sand for each ton of castings produced.

2. In some foundries the consumption of new sand runs as high as 2000 lbs. per ton of castings, the highest reported being about 3000 lbs. In other words, for every ton of good castings produced, from three-fourths of a ton to one and one-half tons of new sand must be purchased.

What Causes High Sand Consumption

3. The action of the molten metal on the silica-clay mixture is quite severe. The intense heat of the metal, 2800 degs. Fahr.

*Sales Manager, Illinois Testing Laboratories, Inc. (formerly with the W. S. Tyler Co., Cleveland).

to 3000 degs. Fahr., causes some of the silica grains which come in contact with the metal to shatter or fracture. Boiling water at only 212 degs. Fahr. will shatter cold glass, and glass is but another form of silica.

4. This intense heat in the mold also burns out some of the bond in the sand. If this fine material—which consists of broken-down silica grains and spent clay bond—is not removed from the sand, it accumulates rapidly. In a short time the sand becomes so contaminated with fines and foreign material that the sand is unfit for further use. When this point is reached, it has been a common practice to discard the sand.

5. The high consumption of sand in steel foundries is due largely to the fact that it has been considered necessary to use new sand, sometimes 100 per cent, as facing in order to obtain satisfactory results.

6. Where all new sand is used as facing, the sand heaps may grow so rapidly that it is necessary to throw away some of the used sand at regular intervals. This is usually done without regard to whether the sand is good or bad.

7. With efficient reclaiming or conserving equipment, and with careful control of the mixtures, the consumption of sand has been reduced to as low as 300 lbs. per ton of castings.

8. In one or two instances, where the same grade of sand is used for both cores and molding sand, reclamation and control has enabled the steel foundry to use all old sand for molding purposes. The only new sand required is for cores. By reclaiming the sand from the cores, this new sand finds its way into the molding sand and replaces the material rejected in the reclaiming operation.

TWO WAYS TO REDUCE SAND CONSUMPTION

9. There are two ways by which the steel foundry can reduce or control the consumption of sand: (1) By reclamation, and (2) by conservation.

10. For the purpose of this paper, we will define reclamation as the recovery of good sand from refuse or waste sand; conservation, as the removal of undesirable material from sand before it becomes so contaminated that it is unfit for molding use.

11. Since the high consumption of sand comes largely as

a result of using new sand as facing, it is evident, therefore, that a reclaiming or conserving installation must turn out a sand, the properties of which are such that it can be used as facing. Unless the reclaimed sand can be used as facing sand, reclaiming or conserving will accomplish little.

REQUIREMENTS OF FACING AND BACKING SANDS

12. In nearly all steel foundries old sand is used as backing. Backing sand, in addition to cohesiveness, has only one main requirement, which is that it must be open enough or permeable enough to allow the escape of gases.

13. A facing sand, in addition to permeability, must be resistant to the high temperature and the chemical action of the molten steel. If it does not have this refractory quality, the sand will "burn in" and, as a result, will not peel from the casting. This causes high cleaning costs and many rejected castings.

WHY SAND "BURNS IN"

14. There are several things which may affect the resistance of the sand to the high temperature of the metal. Some of these are of a chemical nature, while others are physical. The efficiency of the reclaiming installation has considerable bearing upon the physical characteristics of a reclaimed sand.

15. K. W. Grant, former metallographist of the Colorado Fuel & Iron Co., and now metallurgist of the Republic Iron & Steel Co., has made some extensive experiments in an effort to determine why sand fuses or burns in steel castings. In his survey he states that the condition might be caused by four things, namely:

(1) Lack of uniformity in the size of the sand grain.

(2) The amount and distribution of the clay bond and the quality of the clay.

(3) The amount of water used in tempering the clay-sand mixture.

(4) Temperature of steel when cast.

Size and Uniformity of Grain

16. Since the temperature of the steel, the amount of water and the amount, quality and distribution of the clay bond are things that can be controlled within fairly definite limits, Mr.

Grant, in his experiments, worked upon the basis of the size and uniformity of the sand grain.

17. We quote from Mr. Grant's report, the following: "Chemical composition does not appear to be of any particular value in determining the suitability of the sand to withstand fusing. From what has been written on the subject of sand for steel castings, the size, shape and uniformity of the particles have a greater influence on the ability to withstand burning in than does chemical composition.

18. "In order to determine whether uniformity of grain size would be helpful to prevent burning in, test molds for gears were made up of 40- and 60-mesh sand. After casting, the sand left the castings quite freely and showed little evidence of fusion. Over a considerable period of time, experiments were made using the 40-60-mesh sand on castings, the shape of which was apt to be troubled by burning in of the sand. In every case, regardless of the shape of the casting, the sized sand showed a decided improvement."

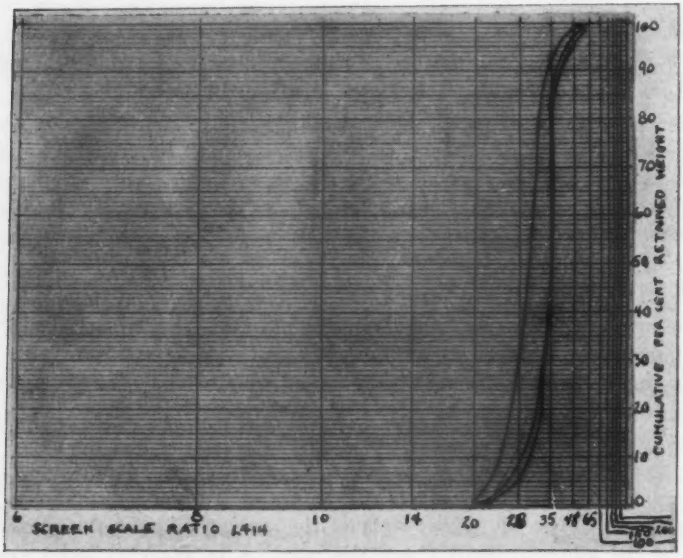

FIG. 1—SIEVE ANALYSES OF SANDS USED IN THREE DIFFERENT STEEL FOUNDRIES.

Ramming Another Factor in "Peeling"

19. It is the opinion of many steel foundrymen that ramming also has considerable influence upon the manner in which the sand "peels" from the castings. It is claimed that uniform hard ramming lessens the tendency for the sand to stick to the casting.

20. John Howe Hall, in his book *"The Steel Foundry,"* states that in a sand for steel molding purposes "the larger the amount remaining on the 20-, 40- and 60-mesh sieves, the better the venting properties of the material. Some foundrymen prefer coarse sand, in which the greater part remains on the 20- and 40-mesh sieves, others get the best results from the finer sand, the greater proportion of which remains on the 40- and 60-mesh sieves." Mr. Hall adds that "whichever end of the scale is preferred, the greater the uniformity of the grain size, the better."

A Study of Grain Size

21. The author of this paper, in cooperation with the W. S. Tyler Co. laboratory staff, has had an opportunity to analyze,

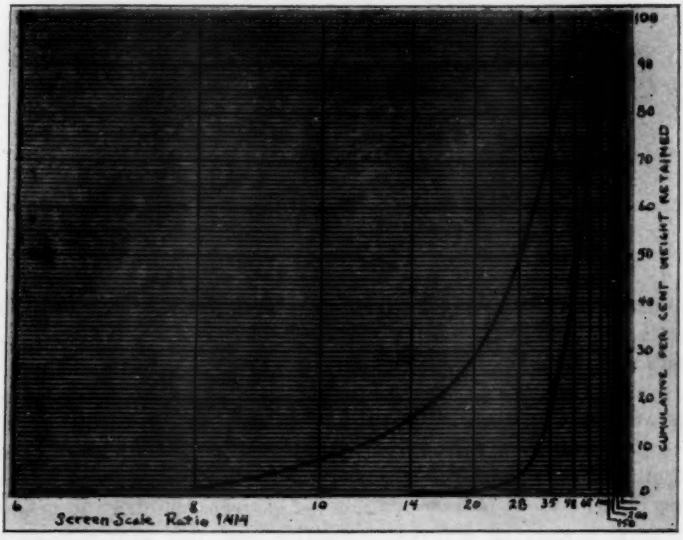

FIG. 2—SIEVE ANALYSES OF RECLAIMED STEEL SANDS FROM EASTERN FOUNDRIES.

from a grain-size standpoint, samples of sand from nearly two hundred steel foundries in the United States and Canada—about one-half of all foundries listed which produce steel castings. Our experience substantiates Mr. Hall's statements.

22. Foundries in the eastern section use a sand which is somewhat finer than the sand used in the Middle West. Western steel foundries, as a rule, also use a finer sand than Midwest foundries.

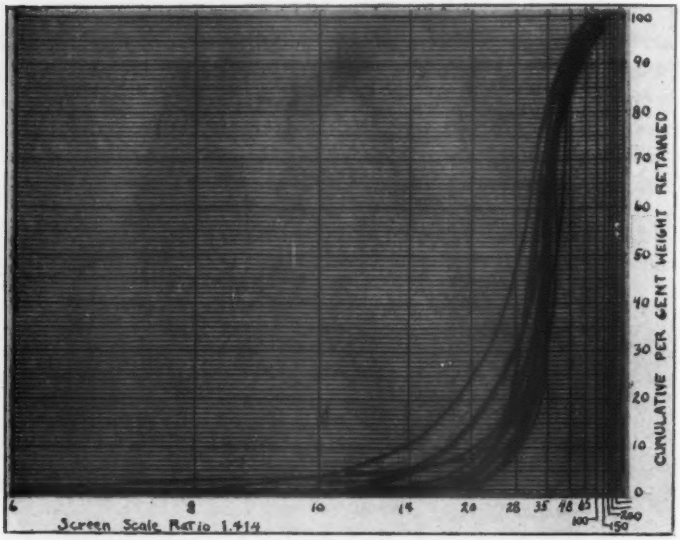

FIG. 3—COMPOSITE SIEVE ANALYSES OF FOURTEEN SAMPLES OF RECLAIMED SAND FROM MIDWESTERN FOUNDRIES

23. This variation in grain size is due to the kind of sand available within the locality of the foundry. However, some foundries are having sand shipped a considerable distance, paying high freight—in some instances as high as $10.00 a ton—in order to secure the sand they desire.

24. Within the past year or so, however, many silica-sand producers have equipped themselves to furnish sand graded to specifications. It is now possible for eastern foundries to get as uniform a sand as Midwest foundries, and this also will soon be true in the Western district.

25. The chart of Fig. 1 shows the sieve analyses* of sands used by three different steel foundries which, in our opinion and so far as grain size is concerned, is the ideal sand for producing medium and heavy castings in green-sand molds. It is interesting to note that there is very little variation in the grain size of these three sands.

26. These sands which pass through the 20 mesh, with 95 to 98 per cent retained on a 48-mesh sieve, are somewhat coarser

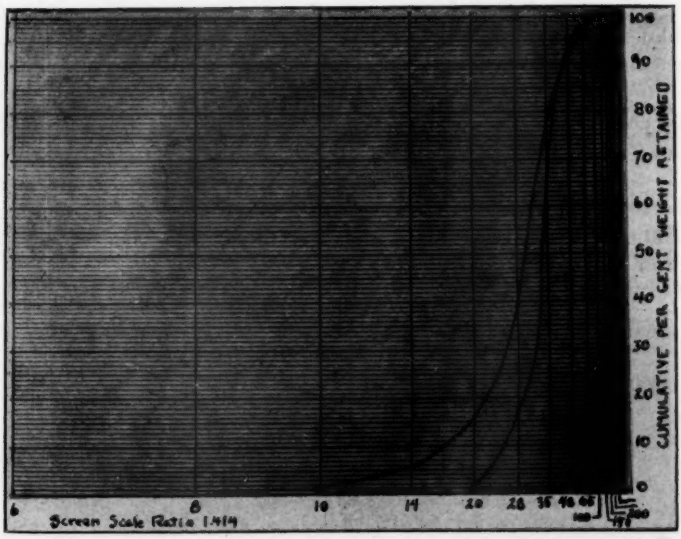

FIG. 4—SIEVE ANALYSES OF TWO RECLAIMED SANDS OF WESTERN FOUNDRIES USING GREEN-SAND MOLDING METHODS.

than sand used by most steel foundries. However, these examples indicate a tendency toward a coarser and more uniform sand. In these three particular foundries, green-sand molds predominate.

27. The chart of Fig. 2 shows the sieve analyses of two samples of reclaimed sand from steel foundries in the eastern section. It will be noted that in one case the sand is quite fine, while in the other case the sand is coarse.

*The curves of the charts in Figs. 1-5, inclusive, are plotted on the Tyler Standard Screen Scale, giving a cumulative direct diagram of screen analysis.

28. The chart of Fig. 3 shows the composite screen analyses of 14 different samples of reclaimed sand from Midwestern foundries. It will be seen there is very little variation in the size. Most of these sands pass a 14-mesh sieve, with 95 to 99 per cent remaining on a 60-mesh sieve.

29. Fig. 4 is a chart showing the analyses of two samples of reclaimed sand taken from Western steel foundries. These samples also check quite closely. Sands shown in Figs. 2, 3 and 4 are from shops where green-sand molds predominate.

30. The chart of Fig. 5 shows the analyses of reclaimed sand from seven different steel foundries where dry-sand molds predominate. With one exception, these sands also are quite uniform. In this exception, the sand is extremely coarse, with all passing an 8-mesh sieve and 97 to 98 per cent on a 35-mesh sieve.

31. By comparing the analyses of the reclaimed sand from these 25 different foundries, it will be seen that a sand passing a 14-mesh or 20-mesh sieve and remaining on a 60-mesh or 65-mesh sieve is the size that has been found most satisfactory.

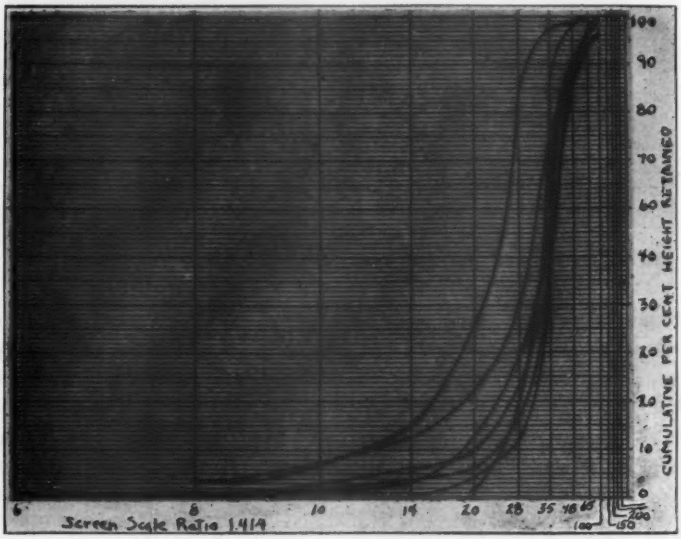

FIG. 5—SIEVE ANALYSES OF SEVEN RECLAIMED SANDS FROM DIFFERENT FOUNDRIES USING DRY-SAND MOLDING METHODS.

Micrographic Study

32. Fig. 6 is a photomicrograph of reclaimed sand. The analysis of this sand is similar to that shown in Fig. 1; that is, all passing 20-mesh and about 98 per cent remaining on a Tyler 48 or U. S. 50 sieve. Note the uniform size of these grains and the absence of fine material.

33. Fig. 7 shows a photomicrograph of the fine material removed from the sand. To determine the composition of the fines, we divided a number of these samples, using Tyler 60, 65, 100 and 150-mesh testing sieves. Figs. 8, 9, 10 and 11 show the material into which these fines divided.

34. Of the total fines, about 25 per cent passed through a 150-mesh sieve. Approximately 30 per cent consisted of silica grains between 100 and 150 mesh. The remainder, or 10 to 15 per cent, was border-line material between 60 and 65 mesh.

35. Fig. 8 shows the material passing the 150-mesh testing sieve, consisting almost wholly of clay dust. Removing only this fine dust still leaves the fine silica grains in the sand, and these fine grains result from the fact that the larger grains have been shattered and broken down by the intense heat of the metal. As a result, an excessive amount of new sand must be used in the facing in order to secure clean castings.

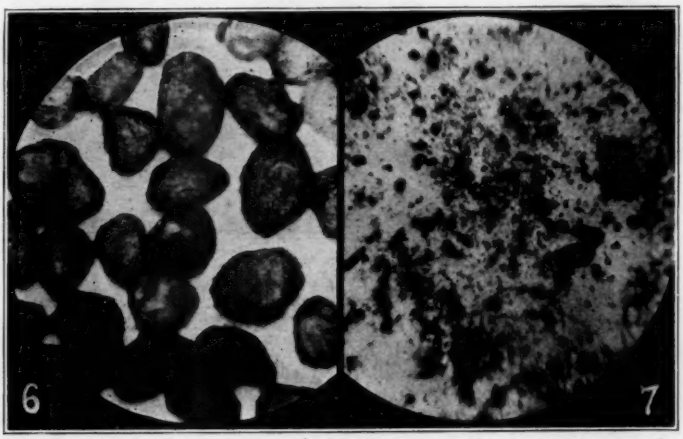

FIG. 6—PHOTOMICROGRAPH OF RECLAIMED SAND OF TYPE SHOWN IN CHART OF FIG. 1. MAGNIFIED 20 DIAMETERS.

FIG. 7—PHOTOMICROGRAPH OF FINE MATERIAL REMOVED FROM A SAND IN RECLAIMING PROCESS. MAGNIFIED 20 DIAMETERS.

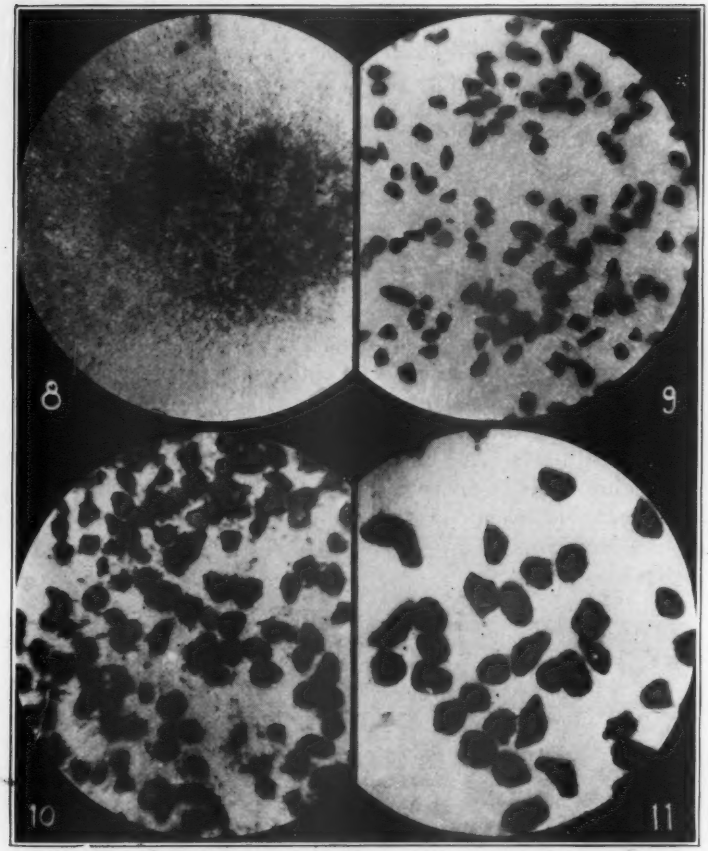

FIG. 8—MATERIAL PASSING 150-MESH SIEVE. MAGNIFIED 20 DIAMETERS.

FIG. 9—MATERIAL PASSING THROUGH 100-MESH RETAINED ON 150-MESH. MAGNIFIED 20 DIAMETERS.

FIG. 10—RECLAIMED SAND PASSING 65-MESH BUT RETAINED ON 100-MESH. MAGNIFIED 20 DIAMETERS.

FIG. 11—MATERIAL PASSING 60-MESH AND RETAINED ON 65-MESH. MAGNIFIED 20 DIAMETERS.

36. Fig. 9 shows the material lying between the 100-mesh and 150-mesh sieves. It will be noted that nearly all of this material is in the shape of fine silica. These fine grains result from the fact that the larger grains have been shattered and broken down in use.

37. Fig. 10 shows the material lying between the 65- and 100-mesh sieves. This material likewise consists largely of broken-down silica.

38. Fig. 11 shows the border line material or the near-mesh particles, that is, the material lying between the 60- and 65-mesh testing sieves. A little of this material, if allowed to remain in the reclaimed sand, will do no harm, although for the average work even this material should be removed as far as possible to do so.

Size of Casting and Type of Furnace

39. Foundries which are producing only light castings can use, of course, a finer sand than foundries producing medium to large castings.

40. Furthermore, the type of furnace used has a bearing upon the temperature of the steel, and this in turn has a bearing upon the size of the sand. Electric steel castings are usually poured hotter than open-hearth steel castings, and as a result the sand for electric steel castings must have greater resistance to heat than for open-hearth castings.

41. Whether dry- or green-sand molds are used, determines to a considerable extent the characteristics of the sand.

WHY SOME ATTEMPTS AT CONSERVATION OR RECLAMATION HAVE FAILED

42. In our experience there are two main reasons why some attempts at reclamation have been failures. The first reason is because the foundry does not give proper attention to the condition of the sand when it goes to the reclaiming equipment. In other words, they attempt to handle it too wet.

43. If the sand is not dry enough for the individual grains to spread apart, no separating process can efficiently remove the fines and dust. We have seen several examples of this. As long as the foundry screened sand that was comparatively dry, the reclaimed sand was free from fines and gave splendid results when used in the facing mixture.

44. At times, however, due either to rush of work or lack of attention, sand containing excess moisture would be fed to the reclaiming unit. Naturally, when the wet sand came from the unit very little of the fines had been removed. This sand was then used in the regular manner as facing, and as a result the casting finish suffered. As soon as this condition was corrected, the results immediately improved.

How Dry Should Sand Be?

45. The question is often asked, "How dry must the sand be in order to be able to remove the fines efficiently?"

46. Since the fines and dust are only liberated when the sand is dry, it follows that the drier the sand, the more thorough will be the fines removal. Sand that carries too much surface moisture will cause the fine grains to adhere to the larger grains and, regardless of the type of separating process used, an efficient removal of the fines cannot be accomplished.

47. There is no dust in a mud ball. Neither are there any free fines in wet sand. However, if the separating process used is efficient, sand that is dry enough to flow through the fingers is dry enough to permit a fairly thorough removal of the fines.

48. The second reason for reclamation failures is because the equipment used for separating the sand was not of a type suited for efficient removal of the detrimental material or the recovery of the good sand. The equipment left a considerable quantity of detrimental fines in the sand; as a result, an excessive amount of new sand had to be used in order to offset the bad effect of the detrimental fines.

49. It has been our experience that new sand must be used in the facing mix in proportion as the fines are allowed to remain in the old sand.

GREEN SAND MOLDS

50. The green-sand molds must have a high permeability to permit the rapid escape of the large quantity of water vapor which is driven off in the mold.

51. Preston, in a recent article,[1] says that one cubic inch of sand will give off 30 cu. in. of water vapor for each per cent of moisture contained. The average moisture content for green

[1]Preston, H. T., *Heap Sand Causes Trouble.* The Foundry, Mar. 1, 1929, Vol. 57, pp. 205-206.

sand molds is 4 per cent—therefore, for each cubic inch of sand, 120 cu. in. of water vapor is formed in the sand which lies close to the metal, and a corresponding amount for the sand farther from the metal.

52. It has been the common practice to use a sand of coarser grain size for green-sand than for dry-sand molds. With no provision for the removal of the fines accumulation, it has been difficult to maintain a satisfactory permeability for pouring in green sand, and for this reason dry-sand molds have been used even for medium and light castings.

53. With the use of reclaiming equipment, a number of foundries which formerly made part of their work in dry-sand molds find that they can change to green-sand molds and secure just as good results, because a satisfactory permeability can be maintained.

Moisture Counteracts Temperature of Molten Steel

54. The moisture in a green-sand mold tends to dissipate the heat of the molten metal. The surface of the casting solidifies before the sand lying next to it can fuse, provided, of course, that the sand is of the proper composition and that it is not too fine.

55. Steel can be poured in green-sand molds at a higher temperature and with as little burning-in as when poured at lower temperature in dry-sand molds. It is not uncommon for steel foundries using green-sand molds to report that they can use 90 to 100 per cent of reclaimed sand for facing and secure as good or even better results as when using a large percentage of new sand.

56. Since there is always some loss of sand in the reclaiming operation—such as fused or hard-burned lumps and sand which breaks down and is removed as fines—there must be enough new sand added to replace this loss.

57. In some foundries enough new sand may find its way into the heap through the cores to replace this loss in reclaiming. In other foundries the percentage of cores may not be great enough and some new sand may be needed to maintain the heaps. In some cases this may be only a few per cent; in other cases as high as 25 per cent is required. The place to add this new sand is in the facing at the time of mulling.

DRY-SAND MOLDS

58. In a dry-sand mold there is little or no moisture to cause steam; therefore, permeability is not so important as resistance of the sand to the action of the molten metal. The refractoriness of the sand is of prime importance in the dry sand mold.

59. It has been a general custom to use slightly finer sand for dry-sand than for green-sand work. This, as has been mentioned before, is probably due to the fact that a satisfactory permeability is obtained in dry-sand molds even with the finer sand.

60. The finer the sand, however, the quicker it will fuse at a given temperature, even though fine sand grains have as high a fusion point as the larger grains. It is just like a snowball and a snowflake. In contact with heat, the snowflake instantly disappears, while the snowball requires longer exposure before being greatly affected.

61. The sand must resist the high temperature of the steel until the surface of the metal solidifies. The larger grains have a much better chance of doing this than the finer grains.

62. By comparing charts of Figs. 3 and 4, it will be seen that the average grain size of reclaimed sand for dry-sand molds is coarser than for green-sand molds.

63. Only recently has it been considered practical to reclaim sand for dry-sand mold facing. The reason for this, no doubt, has been due to the fact that attempts have been made to use old sand as facing without first ridding the sand of detrimental material. Naturally, difficulty was encountered with such sand, and for this reason it has been considered impossible to use old sand as facing.

64. Indications are that a smaller percentage of reclaimed sand can be used for dry-sand facing than when used for green-sand facing. However, 50 to 75 per cent of facing for dry-sand molds can be made by properly reclaimed sand, and excellent results secured.

MOISTURE FOR TEMPERING RECLAIMED SAND

65. Reclaimed sand can be tempered with less moisture than sand not reclaimed and yet develop the same bond strength. The reason for this is that the fines take up water. The finer

the sand, the more surface is exposed and the more water is needed to obtain the desired bond strength.

66. This is an important point to consider. It is especially important for foundries using dry-sand molds. The less water that is required for tempering, the quicker the molds can be dried and the cheaper will be the cost of drying.

67. In green-sand molds, the less water required to temper the sand, the less water vapor or steam will be generated in the mold.

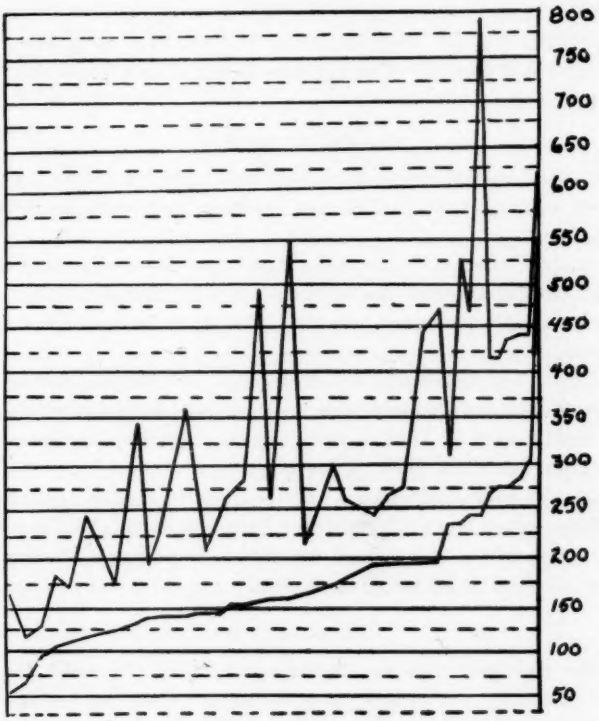

FIG. 12—COMPARATIVE PERMEABILITY OF FORTY DIFFERENT SAMPLES OF STEEL MOLDING SANDS.

Original Sand Average.....323.70 (A. F. A. Permeability)
Reclaimed Average .....178.33 (A. F. A. Permeability)
Average Permeability Increase.... 81.5 Per Cent

PERMEABILITY

68. Sand which contains fines has a much lower permeability than sand which does not contain fines. This is because the fine grains fill up the voids in the sand. The greater the spread of grain size in the sand, the lower the permeability.

69. Fig. 12 shows the comparative permeability of 40 different samples of steel molding sand. The lower line of the chart shows the range of permeability of the sand with the fines. The upper line shows the permeability of the same sand after the fines have been removed.

70. These permeability readings were taken on the old sand mixed with five per cent moisture but without additional clay bond and not mulled. The average increase in permeability was 81.5 per cent.

CONSERVATION

71. Some foundrymen as well as engineers contend that it is just as important to have an open-backing sand as an open-facing sand.

72. Of course, it is important that the steam and gases escape readily through the entire mold. In most instances, however, it is only necessary to remove the fines from the sand used as facing.

73. When the molds are shaken out, the coarser facing sand is mixed with the backing sand, and this will keep the entire heap sufficiently open so that it may not be necessary to remove the fines from the sand used as backing.

74. In some foundries it may be found desirable to eliminate the fines, or at least a portion of them, from the backing sand. This is true if the purpose of the unit is to conserve the sand, or where all sand is prepared as facing.

RECLAMATION

75. In the refuse or waste sand from the steel foundry there is a high percentage of good sand. This percentage may often amount to 60 or 80 per cent of the refuse sand. These good sand grains, when efficiently recovered, can be used in place of new sand.

76. Reclamation, as has been said before, means nothing more nor less than the recovery of good sand from waste or refuse. It is, in the final sense, a sizing process. Refuse sand

can be compared to a barrel of apples, some of which are spoiled. The whole barrel of apples would not be used to make a good cider, but if the good apples are picked out from the barrel they will make good cider.

77. It is the same with sand. In the one case you can reclaim the apples by picking them over by hand; with sand, it must be done rapidly, efficiently and at low cost if the reclamation is to be most profitable.

78. If the system used permits deleterious material to remain in the recovered sand, trouble will be experienced. The sand will not have its highest resistance to the heat and the desired permeability may not be obtained. Improper separation may defeat the purpose of reclamation, as the experience of some steel foundries has shown.

EQUIPMENT REQUIRED

79. There are two general types of equipment in use for reclaiming or conserving sand, namely:

(1) A two-surface, efficient vibrating screen which removes simultaneously the coarse foreign material with the upper screening surface, and the detrimental fines with the lower surface.

(2) A screen combined with air suction. The screen—either the revolving type or an enclosed single-surface vibrating type—is used to remove the foreign material at 6-mesh to ½-in. clear opening. The air suction draws off the fines and dust while the sand is agitated by the screen.

80. For large tonnages the combination screen and air-suction method is considered by some more economical, but definite control over the grain size of the sand is more difficult.

81. It naturally follows that a different type of installation is required for conserving the sand than for reclaiming only.

Conservation Installations

82. There are two general methods of conserving sand, as follows:

(1) By treating all the sand used in the foundry. By doing this, all sand is prepared as facing sand. In other words, all of the sand used in the foundry receives uniform treatment. In this way the foundryman can have absolute control over all of his sand, and for some type of work the results obtained may warrant the investment and expense of so doing.

(2) By treating only a part of the old sand and using it as facing. This is merely taking a percentage of heap sand, removing foreign material and undesirable fines and using the cleaned sand in the facing mix. This treated sand finds its way back to the heap after shakeout.

83. This coarse facing may be sufficient to keep the entire heap open enough so that it is not necessary to remove the fines from the heap sand. A considerable saving of sand can be accomplished in this manner, but perhaps at a sacrifice of definite control over the heaps of backing sand.

84. Where it is desired that the installation handle all of the sand in the foundry, it naturally must be quite elaborate, since conveying and handling equipment must be used for economy.

85. In addition to conveying and elevating equipment, an installation of this kind usually consists of a magnetic pulley to remove nails, wires and scrap metal; a crusher or lump breaker for breaking down the lumps of sand; a means of removing the foreign material and excess fines; a muller for rebonding the sand, and sometimes also an aerator after mulling.

86. Just how far it is necessary to go will depend upon the requirements in the individual foundry. Where the installation is intended to handle only part of the sand for facing use, the installation can be fairly simple. Ordinarily, all that may be required is a means of removing efficiently the undesirable material and fines and rebonding the reclaimed sand.

87. With some simple method of feeding the sand to the reclaiming equipment, often all that is necessary is an efficient two-surface vibrating screen with a small bucket elevator or belt conveyor to give a uniform feed to the screen. With an efficient vibrating screen it is not necessary to use any other auxiliary equipment to help make the separation.

88. In some cases where floating dust is excessive, a dust collector may be found an advantage in order to make working conditions more pleasant. However, with a fully-enclosed, practically dust-proof type of screen, dust can be kept to a low point.

89. For the average shop a simple installation of a screen and elevator can be fitted in to very good advantage and it will be found highly profitable.

Reclamation Installations

90. The purpose of a reclaiming installation is to recover usable sand from waste or refuse. Instead of discarding a large percentage of sand daily and replacing this with new sand, the usable sand from waste can be reclaimed and only the coarse material and fines rejected.

91. A reclaiming installation can be comparatively simple. The tonnage of sand to be handled is not large and an expensive installation is not necessary. For most shops an efficient two-surface vibrating screen will be found most economical for recovering the good sand.

92. A small bucket elevator with an economical means of conveying the sand to the mixer may be all that is required. If an overhead crane is available to transport the sand to the reclaiming installation, the problem is simplified.

93. Using a steel-encased elevator with a receiving hopper provided with a grating, the sand can be fed to the reclaiming unit by shoveling. The grating will hold back the larger lumps of sand, which can be broken down with the back of a shovel. Some lumps are removed by the screen which still contains good sand, but these can be returned to the unit and will be further broken down so that all of the good sand eventually will be recovered.

94. A short belt feeder with a magnetic pulley may be an advantage, especially if there is any quantity of metal in the sand. For most reclaiming installations and the type of conserving installation used to prepare sand for facing, the object desired is to recover sand which can be used in the facing mixes.

95. Where the tonnages to be reclaimed are small, a small two-surface screen may make a complete reclamation unit. In such cases the sand is fed to the screen by shoveling.

96. The type of installation suitable for the individual foundry can only be determined after studying the requirement and knowing just how far it is desirable to go in connection with handling equipment.

CONCLUSIONS

97. The conclusions which can be drawn as a result of these tests and observations of more than fifty reclaiming installations are as follows:

(1) That the efficiency of separation at the desired point is of utmost importance.

(2) That a properly reclaimed sand can be used to a very large extent as facing to replace new sand.

(3) That, for a large percentage of steel foundries, a sand which passes a 20-mesh testing sieve and reclaimed on a 60- or 65-mesh sieve is most desirable.

(4) That the most satisfactory use of reclaimed sand can only be obtained in combination with intelligent control of mixes.

(5) That, with proper equipment, 50 per cent to as high as 75 per cent of former sand consumption can be saved.

(6) That a conserving or reclaiming installation can be simple, yet result in a maximum saving of sand.

ACKNOWLEDGMENT

98. The author wishes to acknowledge the splendid co-operation given by M. H. Tielke, Crucible Steel Casting Co., Cleveland, in making tests and experiments, and for the opportunity to observe the result of reclamation over a period of three years. We also wish to thank K. W. Grant, Republic Iron & Steel Co., for permission to use the data which he collected while making a long series of experiments.

99. Furthermore, we wish to express appreciation for the hearty cooperation of the laboratory staff of the W. S. Tyler Co. in making the hundreds of tests which have formed the basis of this paper.

(Discussion of the preceding paper is combined with discussion of the following paper, and begins on page 321.)

The Most Potent Variable

By Geo. Batty,* Philadelphia

Abstract

A study of light steel casting production has convinced the author that, as about 95 per cent of the defects investigated resulted from some deficiency of the mold, molding sand must be considered the chief variable in production of these castings. Molding sand, consisting of silica sand, binding media and water, is discussed from various angles, such as the importance of grain shape and size, surface area to be covered by binder, bond additions, permeability of facing and backing material, surface moisture and pouring temperature. The ideal grain shape is that of the sphere, and sands approximating this shape are available in adequate quantity. Fireclay used as bond may lead to trouble in re-used sand through accumulation upon sand grains. It is suggested that fine-grained sand requires a longer milling time than a coarse-grained sand when the proportion of bond, by weight, is constant. Permeability of backing sand should be at least equal to and preferably greater than that of the facing sand. Supervision and control of constitution of backing sand is of equal importance with that exercised in preparation of facing sand. Moisture content of the sand near face of mold is rapidly vaporized when metal enters the mold but is cooled and forms a dangerous condensate film, approximately parallel with the mold metal interface. Significance of this condensate film in its relation to permeability of facing sand and of backing sand is discussed. Pin-hole penetration and blows are likely to be more prevalent with an excessively moist sand than with a sand of correct moisture content, provided permeability conditions are equal. Air drying is advocated whenever possible.

1. This paper is intended primarily for the scrutiny of steel foundrymen, and it is intended to treat briefly herein the subject of the production and control of green-sand facing in its application to the manufacture of steel castings.

2. The writer, in the course of his work, has to investigate certain troubles experienced in the production of light steel castings, and has come to the conclusion that approximately 95 per

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cent of the defects in the steel castings that have been the subject of his investigation resulted from some deficiency of the mold, rather than from any inherent shortcoming of the metal. The molding sand, therefore, must be considered the chief variable in the production of light steel castings.

3. Samples of the metal may be taken before it leaves the furnace and an assurance obtained that it will fall within the chemical specification governing the particular heat being made. and that the steel will have physical properties falling within the range generally predicated by the specific composition.

Operators Skilled in Controlling Metal Qualities

4. In acid electric-furnace practice, it is a matter of only a few minutes' work to secure an accurate determination of the contents of carbon and manganese in a bath sample. The operators of such furnaces have arrived, in general, at an ability to control the furnace conditions so that the adjustment of composition may be achieved by the addition of the requisite alloys to produce whatever is demanded by the specification.

5. The condition of the metal before the addition of the alloys—in alloy steels covering whatever special elements are desired, and in plain carbon steels covering the addition of the finals, ferrosilicon and ferromanganese—and the condition of the metal after the alloy additions have been made, is readily ascertainable from a scrutiny of bath samples. In a similar way, a close approximation of the temperature of the metal and of its fluidity (the two are not regularly consonant) may be obtained.

6. Furnace control, therefore, does not represent a very serious variable when skilled operators are available.

7. The casting must be considered as a summation of the qualities of the steel and the mold, together with the properties of the molding medium. It is not proposed in this paper to discuss at any length the mechanical technique of molding, but rather to confine attention almost entirely to the materials used in the production of the mold. In green-sand practice these materials consist of silica sand, binding media and water.

Sand Grain Shape Important

8. For green-sand work it is now generally conceded that the ideal grain shape of the sand is a sphere, and that the more nearly the grain shape approximates the sphere, the more suit-

able is the sand, as regards grain shape, for green-sand molding. In this country there is a plentiful supply of silica sand of sub-angular grain shape, uncontaminated by the incidence of any serious amount of acutely angular or spicular particles.

9. A washed silica sand of good grain shape is considered a very satisfactory base for the production of a green-sand molding medium, and at the present time the attention of many steel founders is turned upon the question of defining the range of grain size of such a favorably shaped sand as will be most suitable in the production of their castings.

10. Irregularity of grain size is considered undesirable because of the "filling" effect of small grains in what normally would be interstices between the larger grains.

Molding Sand Factors Which Should be Considered

11. Some of the points to be considered may be listed as follows:

(a) Area to be covered by bond.

(b) Type of bond.

(c) Bond diluent.

(d) Interparticle atmosphere.

(e) Proportion of water.

(f) { Ramming
Density
Mold resistance

Grain Size

12. Mechanical properties of a certain order must be secured in facing sand if we are to be assured of the ability of the mold to withstand the pressure and the erosive action of the metal. It is obvious that an extremely coarse sand would produce castings of poor superficial appearance, due to the inequalities of a mold face.

13. In addition to this deficiency, there is a liability, with coarse sand, to the detachment of individual grains of sand which might be entangled in the metal and reveal defects in machining, but for some years clean silica sand or washed silica sand of irregular grain size was in common use and was competent to produce castings of good superficial appearance. The small particles distributed through the main bulk of coarse grains

produced a satisfactory face on the mold and a fairly satisfactory surface on the castings.

14. The deficiencies of mixed grain size, however, manifest themselves in a tendency to cause certain types of defects when the total of bond, or bond and silt, is too high. Again, an excessive amount of moisture would also cause blows from corners of the mold and pin-hole penetration at internal angles of the castings, unless the mold corners were well radiused.

Some Effects of Clay Bond Additions

15. When fireclay is used as a bonding medium and any considerable proportion of the used sand is re-used in making a facing mixture, a bad condition arises as the result of the successive films of fireclay drying and hardening upon the original sand grains.

16. This gradual increment of fireclay on re-used sand produces two adverse features, the first of which has already been mentioned—the increase of grain size—and the second of which is the introduction into the molding medium of an excessive amount of perished fireclay, which usually is regarded as silt. The bonding properties of this material are only small and it has been common practice to secure, by feel, an apparently suitable green strength by increasing the moisture content.

17. In such circumstances the sand became unsuitable as a molding medium for castings of high quality. The refractoriness suffered as a result of an extravagant amount of material with a comparatively low fusion point, the permeability was decreased through the aggregation of depreciated bonding material, and the moisture content was increased in an effort to produce satisfactory green strength to allow of comfortable manipulation.

18. With such a sand the liability to defective castings increased enormously and the application of sand testing apparatus gave a prompt indication of the trouble and thereby predicated the first step to be taken to cure the deficiency.

Area of Sand Grains to be Covered by Bonding Material

19. The area to be covered by bonding material has raised, in some quarters, a prejudice against the use of fine-grained sands. It is found, however, that a fine-grained sand will give excellent properties in respect of both permeability and green strength, and with no greater proportion of bond than would be

applied to produce a similar green strength but a somewhat higher permeability in a coarse-grained sand.

20. The relation of total superficial area as compared with mass is not to be taken as a safe index for the proportion of bond to be applied to a molding sand. Nor is it safe to assume that a sand of high permeability will give greater freedom from blows at corners or angles than a finer sand of lower permeability, provided that care is taken in the selection of the fine-grained sand and of the bonding media used. In this connection, we must regard water as one of the bonding media.

21. In relation to the area to be covered by the bond, it should be remembered that a fine-grained sand requires a longer milling time than does a coarse-grained sand when the proportion of bond, by weight, is a constant. And it may be that some founders have criticized fine-grained sand unfairly because they did not make sure that the time of milling was adequate.

22. The type of bond to be used in order to produce the most satisfactory results hitherto has varied with the individual foundries. It seems reasonable to assume, however, that a regularizing of conditions of manufacture in respect to castings of a similar type would result in the determination of the most satisfactory bonding medium, or combination of bonding media, to be used for green-sand work.

Facing and Backing Sand

23. The use of fireclay has been commented upon already, and unless used sand is put through a very thorough reclaiming operation, a sand so bonded is likely to give trouble when any considerable proportion of used sand is applied to make facing mixture. The fireclay-bonded sand also is potentially dangerous, through a steady aggregation of fines, when used as backing sand.

24. The writer would say that, in his experience, facing sand of excellent quality fails to function efficiently if the backing sand is of an inferior, close and impermeable nature. The permeability of a mold—and we must remember that we are concerned with the constitution of the whole of the mold and not merely of the facing—closely approximates the permeability of the worse of the two constituents, facing sand and backing sand.

25. The preparation of heap sand or backing sand is of considerable importance, and control of the moisture content,

bond and green strength must be exercised on the heap sand as well as on the facing mixture. On many types of small castings it is economically sound to use one sand only, making no differentiation between facing and backing.

26. The reclaiming of used sand for use in a facing mixture is a matter requiring considerable attention in the selection of proper apparatus if satisfactory results are to be obtained and the method must ensure the almost complete, if not entirely complete, extraction of the oxide of iron which contaminates the sand at the mold-metal interface.[1]

Bentonite Used as Bonding Material

27. The green-sand practice of the members of the Steel Castings Development Bureau has been modified so that all are using binders of the bentonite type in association with (in some cases) cereal binder. It has been found quite practicable to use 100 per cent reclaimed sand as the basis of the facing-sand mixture by combining a screening and a pneumatic system for cleaning the sand after each cycle of use.

28. The actual mass of bond, when bentonite and cereal binder are used, is considerably less than that of the bond when fireclay is used, while the properties of the molds are more satisfactory than fireclay-bonded molds for the type of castings current in our foundries.

29. The use of bentonite alone or in combination with cereal binder permits, or even demands, the presence of some bond diluent in order to produce a sufficient film of mobile material to coat the grains of sand adequately. This feature is considered quite valuable in that it is possible, under the reclaiming methods now in application, to maintain a silt content of not more than 4 per cent in the reclaimed sand—the silt being all that material which will pass the 100-mesh sieve when a dry sample from the reclaimer storage bin is taken.

30. On the grains of the reclaimed sand there is a small amount of strongly adherent bonding matter amounting, in total, to less than 1½ per cent of the total mass. This strongly adherent bond appears to be quite efficient as a bonding medium when the sand is moistened, and it is found that an addition of only 1½ per cent, by volume, of binders is necessary to pro-

[1] A. H. Dierker, *Reclaiming Steel Foundry Sand*, Amer. Inst. Ming. and Met. Engrs., Technical Publication 261, presented at February, 1930, meeting.

duce satisfactory properties in the reclaimed sand for it to be used as a facing material.

31. Bentonite and cereal binder have such great bonding properties that they may safely be diluted with either silt or silica flour and produce a facing sand of excellent properties. The amount of the total content of bond and silt must be under control if satisfactory permeability is to be secured, and the amount of water must be regularly controlled in order to produce castings free from certain defects.

Factors in Blows and Pin-Hole Penetrations

32. A coarse-grained sand, sub-angular or approximating the spherical form in grain shape, in the absence of silt and in the presence of only a small amount of strong bonding material, will have a high permeability because of its comparatively large inter-particle "voids." To call these inter-particle spaces "voids" is not correct, because such spaces are filled with air and water vapor.

33. The ability of a molding sand to produce castings free from blows and pin-hole penetration is not strictly related to its permeability, and many instances have come before the writer's notice of high-permeability sands causing a blown condition in the castings. The highly permeable facing is most dangerous when it is backed by a close, relatively impermeable backing sand.

34. Thus, a good principle to observe in the manufacture of green-sand castings is to ensure that the permeability of the backing sand is not less than that of the facing sand.

Moisture of Sand Near Casting Surface

35. The moisture content of the sand near the face of the mold, and the inter-particle atmosphere of the sand, may be considered as being in combination to promote defects in the steel casting. This statement is not made in any alarmist manner, but as a cold expression of fact—the defects in such rejected castings as the writer has been called upon to examine being traceable, in the large majority of cases, to mold deficiencies.

36. Blows and pin-holes are formed primarily as a result of the injection of gases from the mold into the casting. Our investigations appear to indicate that the moisture content of the

facing, near the interface of mold and metal, is the chief culprit in forming such defects.

37. When metal enters a mold, the moisture at the surface of the mold in contact with the metal is very rapidly converted into steam and is driven back from the face of the mold through the pores, or interstitial spaces, of the sand. In the same period in which such steam is generated, the inter-particle atmosphere of the sand is also enlarged and the increased volume of atmosphere must readily migrate through the sand if excessive pressure within the mold is to be avoided.

38. A coarse-grained sand has a large inter-particle atmosphere, and unless the permeability of the whole of the mold is maintained there may be some injection of this expanded atmosphere into the casting at re-entrant angles.

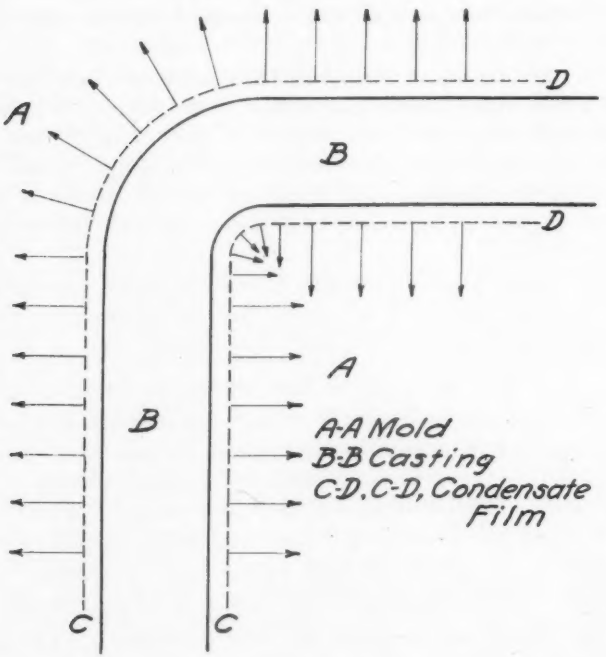

FIG. 1—SECTION THROUGH A SIMPLE MOLD AND A CASTING, ILLUSTRATING FLOW OF GASES ON POURING.

39. The moisture of the mold, however, is considered by the writer to be most active, when sand conditions are not sufficiently good, in producing blows and pin-holes.

Moisture Near Face of Mold

40. In discussing the permeability question, a number of steel foundrymen have spoken of the ability of the sand to conduct away readily the enlarged atmosphere and the steam generated when metal is poured into the mold. In the writer's mind, such an expression does not comprise the full facts; and it is here suggested that the behavior of the moisture near the face of the mold has not been very well understood.

41. Fig. 1 shows a simple section through a mold and a casting, the solid lines indicating the inter-face of metal and mold. The moisture near the face of the mold, when subjected to the thermal attack of the metal, is rapidly converted into steam. This steam, in a satisfactorily permeable mold, moves away from the mold face along the avenues indicated by the arrows on Fig. 1—that is, through the ducts or inter-particle spaces in the sand.

42. This steam, however, almost immediately comes in contact with sand sufficiently cool to condense it and, consequently, a film of condensate is formed approximately parallel to the face of the mold. As the heat from the metal penetrates the mold, the inner face of this film of condensate will rapidly be converted into steam. The condensate film is indicated on Fig. 1 by dotted lines.

43. The condensate constitutes somewhat of a barrier in the mold and, therefore, when part of the condensate is converted to steam, a belt of acute pressure is likely to be produced between the condensate and the face of the casting, because the permeability of the mold is depreciated locally by the condensate film.

44. If, therefore, the permeability of the mold is so unsatisfactory that pressure is generated in the inter-particle spaces to an extent greater than the tensile strength of the initially solidified envelope of the casting, the envelope or skin of the casting will be ruptured and gases injected into the casting from the mold.

45. On such an assumption is based the belief that the moisture content of the sand must be maintained at the lowest

practicable level, and that, wherever possible, green-sand molds should be allowed to air dry.

Where Blow and Pin-Hole Troubles Occur

46. Further reference to Fig. 1 will show that at a corner or angle of the mold the enlarged or expanded gases are partially entrapped at the corners. The proportion of metal to mold at a corner or angle of a mold is considerably increased as compared with the relation of metal contact with mold at any plane face.

47. The heat attack of the metal being much greater at a corner or angle of the mold, it is safe to assume that the generation of steam, and the expansion of inter-particle atmosphere, will be consonantly greater. As the facilities for escape of enlarged atmosphere are diminished at a corner or angle of a mold, it is at these precise locations that trouble from blows or pin-holes may be expected.

48. The film of condensate receives at this place the most rapid and vigorous thermal attack of the metal; thus it seems reasonable to assume that, at any internal angle of the mold, the maximum of pressure will be generated as the condensate is reconverted to steam, because the conductivity of the mold for gas, water vapor or water is decreased at this particular location.

49. This matter is briefly touched upon in relation to a test mold in a previous paper[2] by the writer.

Air Drying Is Desirable

50. In snap work any appreciable degree of air drying is not practicable, but quite a large proportion of the work made in green-sand foundries may be given air drying over a period of 30 to 40 minutes which will, except in conditions of high humidity, reduce the moisture content at the mold faces from about 3.5 per cent to 2.4 per cent. The face of the mold, to a depth of ⅛ to ¼ inches, is the part that is primarily responsible for the troubles labeled blow and pin-holes, provided that the mold as a whole is uniformly permeable.

51. In other words, a relatively impermeable sand may be made quite suitable to receive hot metal if it is skin dried, whereas a green mold must have considerably more satisfactory

[2] Geo. Batty, *Production of Electric Steel for Castings.* Presented at Cleveland meeting, American Society for Steel Treating, 1929.

conditions as regards bond, silt, moisture content and true permeability if satisfactory castings are to be produced.

Density of Mold and Ramming

52. The density of the mold, produced by ramming, is also related to the formation of certain defects, because excessive ramming decreases the inter-particle spaces and at the same time increases the concentration of moisture as related to volume, although not as related to mass. With decreased volume and a concentration of moisture, the blow and pin-hole troubles are bound to be augmented. Hence, control is necessary in respect of the amount of ramming to be given to molds of various types.

53. It is recognized that no hard and fast rule can be laid down to cover completely or comprehensively the wide range of components that are classed either as light steel castings or as small steel castings. Provisions as to the amount of ramming are predicated almost entirely by experience.

54. However, on machine production it is not impossible to allocate either a definite number of jolts or squeezes to any particular job, and there is no reason why, when the machines are working regularly—with a sufficient supply of air—the molders should not count the jolts in order to arrive more nearly at uniform ramming.

55. The effects of uneven ramming are so well known that in this meeting they need not be enlarged upon except to say that hand ramming in such a manner as to bring the end of the rammer close to the face of the pattern, thereby producing a locally over-rammed spot on the face of the mold, is almost certain to result in a defective casting.

Green and Dry Sand Molds

56. Green-sand practice is not to be considered entirely a means of producing castings at a cheaper rate than is possible when dried molds are used. It is absolutely essential to the satisfactory production of many types of castings that they be made in a mold which offers a minimum of resistance to the contraction of the casting during the change from solidification temperature to shop temperature.

57. Admittedly, many castings are knocked out of the flasks while the temperature of the metal is above 1000 degs. Fahr.; but the bad effects of mold resistance to contraction of the cast-

ing are generated in the higher ranges of temperature below the freezing point of the metal.

58. Engineers and designers demand light and intricate castings as being the most practicable means of securing the components they require. As these components must be free from defects, such as blows and pin-holes, and must also be free from cracks, tears or acute strains, it becomes essential that they be produced in green-sand molds.

59. The resistance of a dry-sand mold to a casting is considerably greater than that of a green-sand mold. Hence, where comparatively light and intricate components are required, the dry-sand method must be ruled out of consideration.

Pouring Temperatures

60. When the superficial area of a casting is large in relation to mass, the sections are bound to be light and, as a consequence, hot metal has to be used to produce these castings true to form. The pouring temperature of the metal to be used for such castings, therefore, must be appreciably higher than that used for more massive castings.

61. The influence of temperature upon those molding media which tend to produce gases when subjected to the heat attack of metal is a matter for serious consideration, and it would be unwise to assess the difference between 2900 and 2950 degs. Fahr. as a difference of 50 degrees in 2900 degrees. So far as the effect on the mold is concerned, we must remember that, when we compare the effect of hot metal and cool metal on a mold, we are dealing with liquid steel. Therefore, we should consider a difference of 50 degrees temperature in relation to the available range of temperature for pouring.

62. On quite large castings the pouring temperature may not safely be below about 2700 degs. Fahr., and it is comparatively rare that the actual pouring of metal from handshanks or bull ladles is conducted at a temperature higher than 2950 degs. Fahr. A difference of 50 degrees in pouring temperature is, therefore, quite a considerable proportion of the operative fluid range of steel for castings, and the question of sand control is tied in with the question of temperature control of metal.

63. The design and nature of the casting may demand high temperature, and the sand—the *most potent variable*—must be

adjusted and controlled in order to produce sound, satisfactory and dependable castings from such metal.

64. This note does not pretend to treat at all fully the subject that has been touched upon. It is believed, however, that sufficient has been said to induce discussion on the points that have been raised and to promote discussion of other points related to this most potent variable in steel foundry practice.

DISCUSSION

ORAL DISCUSSION

(This discussion combines the oral discussion on both of the papers which begin on pages 289 and 309.)

A. H. DIERKER:* In this matter of the peeling of the sand from the casting—or the reverse condition, that of the burning in of the sand—Mr. Pugh has emphasized the fact that grain size is an important consideration. I cannot agree with that.

Anyone who has pulled a casting out of sand while a bright red or yellow in color, and has watched it cool down, probably has noticed a very curious thing. Before it comes down to a dull red heat, a thin skin of sand adheres very finely to the casting. When it reaches a dull red heat, this sand suddenly loosens from the casting and can be brushed off very easily, exposing the clean surface of the metal.

This phenomenon can be explained by the diagram of Fig. 13 to Mr. Pugh's paper, showing the expansion curve for quartz, which is the material of which our sand grains are composed. A sharp break occurs at 575 degs. Cent., or 1067 degs. Fahr., which is a dull red heat.

This change in volume, amounting to about five per cent, is instantaneous and reversible. It will increase in volume going up on the

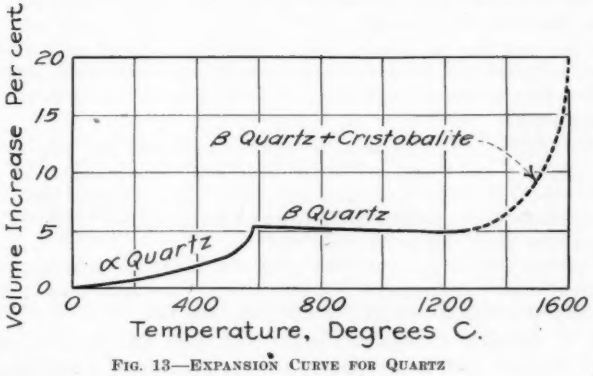

FIG. 13—EXPANSION CURVE FOR QUARTZ

*Ohio State University, Columbus, Ohio.

curve and decrease coming back down. When this temperature of 575 degrees is reached, the sand suddenly contracts. There is no corresponding contraction in the metal, of course, at that temperature.

Only one thing can happen: The sand loosens from the metal. I believe this is an explanation of the peeling of the sand from the metal.

We have found this phenomenon most pronounced when we have a comparatively clean quartz sand with a minimum amount of bonding material in it. As we increase the bonding material, especially clay, the peeling effect becomes less and less pronounced.

In the case of Mr. Grant's experiments, in which he found that sand peeled more effectively when he had a certain grain size, I feel that was due to the fact that he had removed the fine material. We have found that the detrimental elements in the used molding sand are largely confined to finer material, and if Mr. Grant removed that in sizing the sand and then used only the coarser size, he removed, of course, the material that caused his burning in. Probably that, rather than the greater uniformity of sand grains, was what made his peeling more effective.

The finer grains found in the used sand can hardly be attributed to breaking up of the coarser grain. Even in a washed Ottawa sand —which is of comparatively uniform grain size—it will be found that two to three per cent will pass the 150-mesh screen. Of course, if we examine the used sand, which when new is an Ottawa-base sand, finer grains will be found in that used sand. We can hardly say that is due to the grain breaking down—that is, to the breaking down of the quartz in the grains.

In our experiments we have found that the quartz grains, in sand of the size found in sand usually used for steel-molding purposes, usually are very resistant to disintegration by heat.

Perhaps in examining sands under a miscroscope it will be found that the finer grains look very angular, while coarser grains will look rounded. This might lead to the conclusion that the finer grains came from the breaking up of the coarser grains, but this is not exactly true.

Dr. Ries has brought out, in his examination of a large number of sands, the fact that he always found roundness confined to the coarser grains; and that, as the grain size decreased, the angularity increased. This is a natural phenomenon and is not due to the breaking down of the larger grains.

M. D. PUGH: Mr. Dierker, in your experiments did you consider grain size and make analyses along with your experiments? In other words, have you taken new sand and made your analysis, used it and made a subsequent analysis after it had been used two or three times, to determine your change in grain size?

I believe that if you will take your new sand, use it several times, and then make a subsequent analysis after it has been used, you will find there is a decided change in the sieve analysis.

A. H. DIERKER: I doubt very much that there will be a size change, due to the fact that in one plant, after several years' operation, they found only a loss of about 15 per cent in the reclaiming operation due

to removal of fines. This included, of course, excessive coarse material and also the bonding material which had been added and which probably amounted to four or five per cent. Thus there can be, in that case, a very appreciable change in grain size.

M. D. PUGH: Different grades of sand will fracture more readily than others. It depends upon whether it is a crushed sand or a natural sand. If you have dealt with natural sand only, no doubt you have found that your breakage is less than if you were using a crushed sand. I believe most foundrymen who have had experience along these lines will bear me out in this.

A. H. DIERKER: You mean by "crushed" sand, quarzite that has been crushed up?

M. D. PUGH: Taken from the natural rock and crushed.

A. H. DIERKER: Do you find that the breaking up of the crushed quarzite was not due largely to the fact that in crushing quarzite you get very sharp, thin-edged grains? Naturally, material of this sort is bound to break up more readily than sand which is sub-angular or rounded in grain, like the Ottawa sand.

W. H. SPENCER:* Our castings are gray iron. I have observed changes in grain size, starting with the synthetic sand we make up from silica sand, adding our own bonding material. If we start with, say, four per cent coarse—let us call it coarse without giving it a definite number—10 per cent on the next screen, 40 per cent on the next, and so on down, and if, after 24 hours' use we retest, we will find possibly three per cent coarse, the second size will be up to 12 per cent and the third size will gain about one per cent; the finer ones will be about the same.

Following that from day to day, and if no more silica sand is added, a gradually increasing percentage of smaller grains is obtained.

RALPH H. WEST:† Some few years ago we went into this sand question from the standpoint of fineness. The European practice was called to our attention, so we naturally thought that European people had something on us in the quality of sands.

About 1923 I took a trip abroad and visited France and Belgium, and I found that throughout those countries the quality of the sand was at least 25 per cent finer than what we are using here in America. In fact, I think their sands will average close to the 70 or 80 qualities in fineness, where ours average around 65.

There is no doubt that they are getting a very attractive surface on their castings. Of course, in making castings, we have more than sand to consider. We want quality and we want finish. If we are going to go into fine sands, we have to watch the internal strains in our castings.

Some time ago we were called upon to make some tractor shoes for a certain company, and we found that the people who had been

*American Cast Iron Pipe Co., Birmingham, Ala.
†West Steel Castings Co., Cleveland.

making them were using a very fine sand. Naturally the shoes, under tests—breaking tests or load tests—were showing internal strains. If one was put in a vise and a hammer or sledge put on it, it would crack.

We just opened up the sand some 20 points and relieved all the trouble. And still we maintained the quality of the casting.

In this sand problem we have a little more than just the fineness to consider. We want the final casting, so we have to work from both ends.

W. A. HAENDIGES:* As to the efficiency of sand-reclaiming systems, we may want to get a uniform grain size in our sand after it comes out of the reclaimer. These reclaiming systems vibrate the screen on a slope and have, for example, 4 mesh for a top and 60 mesh for a bottom screen.

Taking into consideration the time it is on the screen while it is going down this slope, it will be seen that the efficiency may be impaired. The 60 mesh will contain considerable fines which we are trying to eliminate.

I thought it would be better to have a coarser mesh on the lower screen, around a 35 or a 48 mesh, which would give the same theoretical efficiency of a 60-mesh screen. Again, that 4 mesh, for instance, on the top does not seem to be quite fine enough either, to get rid of our scale. An 8 mesh would be better than a 4—probably it would have the same efficiency as a 4.

Have you done any work along these lines, Mr. Pugh?

M. D. PUGH: Each foundry will have to work out its own grain size more or less to suit its individual requirements.

It is true that one may want to go to a finer screen on top or a coarser screen on the bottom. The separation will be dependent upon the volume of sand being fed to the unit and upon the slope or angle and the uniformity of spread of the sand over the screen. All these factors enter into the result.

It would be difficult, without a study of the conditions, to lay down a hard-and-fast rule as to just what would have to be done in one particular foundry. As a general rule, however, the 4-mesh top and the 60-mesh bottom seems to be quite standard practice.

Some foundrymen favor the coarser and some the finer on both screens. I know of some cases where they have gone as fine as an 80 on the bottom, and other cases where they have gone to as coarse as three-eighths on top. In still other cases they have gone to as fine as 10 and 14 on top and a 35 or 40, or even a 28, on the bottom.

W. A. HAENDIGES: It is dependent on the efficiency of the screen, how much it vibrates and how long the sand stays before it gets off the screen. This is a big factor.

Have you done any work on the relation of different types of sand on their resistance to heating—which will crack upon heating, etc.? Certain types of sand have a greater resistance to cracking than others on subjection to heat—repeated heating and cooling.

M. D. PUGH: I believe, as I said before, that it is a difference between

*Atlas Steel Castings Co., Buffalo.

the kind of sand, the locality from which it is obtained, and the other factors.

F. A. MELMOTH:* Mr. Pugh's paper brought to my mind a great deal of what I suppose is ancient history, and yet which was the beginning, I believe, of this sand question so far as affected by reclamation.

I am not well enough aware of the history of the thing in this country to say just when you started to reclaim sand or when you started to "tumble" to the idea, but some 12 to 14 years ago we started this thing up in Lake & Elliot's foundry at Braintree, England. I had been on the Continent and in a great many foundries in England. I was interested in malleable, I was interested in iron, and it occurred to me that the wastage from the sand standpoint was something terrible in a steel foundry.

I believe that in the steel practice in those days we used an average of two tons of facing sand for every ton of steel we turned out as light castings.

For about twelve months we made sand using hand screens, endeavoring to find out what was the basic fundamental underlying the use of reclaimed sand. After we had done that, we put our heads together and found there was no plant suitable for the purpose on the market. We knocked together an equipment looking like something between a water tank and an elephant, and by the use of a current of air we succeeded in reducing the fines in the sand.

Prior to that time we had produced a regular series of sands by hand screens, and made castings. We had no difficulty in coming to the conclusion that it was quite an easy matter to utilize sand in a reclaimed condition.

I believe that, technologically, the question of reclaimed sand is sound. I am not so sure that, commercially, we see it in its true value. If one puts in an over-elaborate plant in an endeavor to reduce the fines to nothing, all savings obtained can simply be dissipated by the initial capital expense.

I question whether sometimes we do not attach rather too much importance to the influence of the small amount. Personally, I never have attempted to remove the whole of the silt from sand. I have rather a different idea, and I know it is shared by Mr. Batty. In fact, I think that he performed most of the initial thought on this subject—that is, the study of the mechanism of the action of the sand as apart from its mere holding of a body of molten steel.

It would appear to me to be thus: If we put steel into a chill mold, we do not get any of the troubles, yet we are putting it into a completely impermeable body. We feel concerned and fret ourselves terribly about the presence of a small quantity of fines, whereas actually it is not of such great importance. We are seeing the importance of the facing sand out of its proper relation.

We must see the importance of the backing sand much more than we have done in the past. I am speaking now from the English point of view.

*Detroit Steel Casting Co., Detroit.

The quantity of facing sand—the thickness of the facing sand lying in contact with the metal—has a tremendous bearing, and there alone is the possible solution of the difficulty. We know that we contradict ourselves every day of our lives when we carefully remove all the fines from our sand for dry-sand castings, and then mix silica flour with it before use. If we put in too much silica flour, we are in trouble. If we use too great a thickness of the sand containing the silica flour, we are in trouble again.

I suggest that what we are after is a mechanical means of control of the egress of gases which are formed, not in the steel and not exactly at the point of contact with the steel and the sand, but behind it.

I have said before that I acknowledge Mr. Batty's initial thought along these lines, and I believe the theory is right. As a proof of that opinion, many years ago I took the fines out of the sand and made from them perfectly good, machinable castings. It is merely a question of producing mechanical venting behind the facing.

R. A. BULL:* I am always interested in anything Mr. Batty says and in anything Mr. Melmoth writes. Also, I am quite interested in Mr. Pugh's statements. However, I am inclined to agree with Mr. Batty and Mr. Melmoth about the influence of fines.

In my opinion, it is not the total quantity of fines that is apt to be troublesome so much as it is the nature of the fines. Quite a lot of this fine material that is removed in reclamation consists of fragments of a film of what we might consider destroyed binder, which unquestionably is objectionable. When it comes to the very fine sand grains, like the particles of sand that may have broken off by the action of the heat, I do not think they are so injurious.

As a matter of fact, I am inclined to believe, from the standpoint of the peeling of the sand from the castings—putting aside for the moment the matter of permeability and its influence on porosity—that the finer the sand, the more satisfactory the facing is apt to be. In that respect I disagree with Mr. Pugh.

For convenient purposes of illustration, suppose we have a number of sand grains of uniform size, and place them so that they do not come in actual contact with each other because, theoretically, if all the facing ingredients are properly mixed there is a film of binder on each sand grain. Let us assume that, whether we use fine sand or coarse sand, it is all of the same approximately round shape, as well as of approximately the same diameter.

Suppose also that we have a casting formed against this surface of a mold, prepared from sand grains of large diameter. Then consider the same kind of casting in which the sand grains are approximately one-half or one-third that size, having approximately the same closeness of contact as in the other case.

In the first case there is considerably more surface contact of the metal than there is in the second case. That has a decided bearing on the satisfactory peeling of the sand from the casting, or, in other words, what we ordinarily term the refractory property of the sand mold.

*Electric Steel Founders' Research Group, Chicago.

It is not truly refractory, of course. We know that because we see, as the scale drops off, that there is fusion of that sand. It seems to be the objective, practically—whether we have always considered it in the past or not—not to produce an entirely refractory mold case, but to produce a scale or a condition of fusion such as will nicely drop from the casting without a great deal of labor in the cleaning room.

GEO. BATTY: With reference to what Major Bull has just said, Dr. Moldenke gave a very interesting illustration recently at the meeting of the Advisory Committee of the Bureau of Standards. He pointed out that the grain size of the sand was distinctly related to the peeling of the sand from the casting, and he suggests that the metal flows in and makes claws around the individual grains (as diamonds are set), and that these claws may be sufficiently strong to hold a layer of sand on the casting.

I believe that is quite correct, and some of our members will agree with me that this has already been pointed out, repeatedly, to their staffs. Dr. Moldenke was discussing iron castings, but to some extent his comments may be applied to steel castings.

With reference to fineness, I believe it will be conceded, on consideration, that with a fine-grain sand, when dealing with steel poured at a temperature not much above its freezing point, a greater quench effect is obtained from a fine-surface mold than from a coarse-surface mold. That is rather important.

Mr. West's point in discussing Mr. Pugh's paper is well taken, but I will not say that opening up a sand or making it coarse and involving a relatively coarse-surfaced casting is the whole solution. Many of us are doing considerable work in the mechanical relieving of molds by relieving blocks, and in the mechanical relieving of molds by having a fine sand as a facing and a coarse, very permeable sand as a backing.

The point raised by Mr. Melmoth is one we both have discussed very many times. I have tried to impress on our people, in talks to the staffs and by very simple diagrams, that the face of a mold, whether green sand or dry sand, should approach as nearly as possible the ideal condition. This would be expressed as the mold face being impermeable and permeability expressed as increasing with the increase of distance from the mold-metal interface.

Given that condition, an almost ideal condition is present for the production of sound steel castings free from blows and pin holes.

When the condition of the impermeable face is produced in a dry-sand mold, by using an angular sand as the basis material for the facing, in many cases it is loaded with silica flour. Then a silica wash is placed on the surface of that mold, very often reinforced with bentonite used as a dispersion agent. We are then achieving, or are trying to achieve, something approaching this ideal condition of an impermeable mold face —a close, fine face so that contact and the maximum chill effect is obtained on the casting, and increasing permeability as the distance from the mold metal interface increases.

The blow trouble illustrated in Fig. 1 of my paper—which I believe is precisely the mechanism of the trouble—is something that has given

worry to steel-casting makers for a long while. When they try to be economical in the re-use of sand, without proper use of reclamation, they have this pin-hole trouble. In many cases the pin-hole trouble does not manifest itself until after the castings are annealed and tumbled.

This would indicate that the blow occurs on the corner or angle of the mold. When a film of that metal is taken off by annealing and subsequently removing the annealing scale, the mouth of the pin hole is opened up. Many people have gone so far as to say that such holes were put in by annealing.

A. C. JONES:* Mr. Batty, assuming that what you said was true in the corners, would that apply to a flat plane of the casting? In scrutinizing the surface of the casting before annealing, we would not find any evidence of a ruptured skin. I believe that it is possible for those gases, firing back due to the back pressure formed, to be absorbed through that very thin, solidified film of steel. However, if the gases are impregnated into the steel, or if they break through that film mechanically, there should be some evidence of those holes on the outside of the scale.

In many castings which I have examined, I have not found this so; but after heat treating, as you say, and perhaps removing a sixty-fourth of the metal, we find those pine holes underneath. What is your thought about that, Mr. Batty?

GEO. BATTY: I believe this condition is found in an impermeable mold where gases are injected on a plain surface, either horizontal or vertical as poured. I believe the mechanism of the formation of those blows is identical on the plain surfaces and on the internal angles.

Before annealing, if a fairly high-powered microscope is used, the tendency will be to find numerous tiny depressions in the steel. The casting that comes to the laboratory for scrutiny from the annealing room still has a very thin film of oxide on it, and the edges of those holes, if they are very tiny, are oxidized more than anywhere else because of the access of oxygen to the very thin neck of the blow.

The liquid interior forces back the ruptured envelope when the pressure is relieved. It is an incidental blow, but a very small amount of moisture will cause a blow cavity of one cubic centimeter. Very often there will be a hundred pin holes to a cubic centimeter, the individual blows being small.

The envelope being ruptured, it folds back, before rupturing it elongates and the first motion of the injecting gas is to distort the envelope. Thus, when the gas bursts through, the edges of the ruptured envelope are pressed back by ferrostatic pressure, and the wound is healed. There is no easily visible scar.

In machining or grinding castings, just the surface is taken off with the grinding wheel, and a number of small holes will be seen. If the casting is ground 1/64 in. deeper, those holes are two to three times the diameter, at the new surface, of those first observed.

I believe this to be the explanation of the formation of pin holes, but I am awaiting a conviction of error.

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*Lebanon Steel Foundry, Lebanon, Pa.

H. E. MOONEY:* Did I understand Mr. Batty correctly to say that the shape of the blow hole makes little difference, so long as it is eliminated?

I believe that we ought to educate the boys in the foundry, especially our inspectors, so that when they report a casting having blow holes to the foundry superintendent, they will be able to tell why or what kind of a blow hole it is. We have various kinds. We have the blow hole from metal that is not thoroughly deoxidized, the blow hole from a regular blow, from slag, and also from shrink.

We have the various pin holes which have been discussed. We have another hole I would like to have someone speak about if he can, and that is the silicon hole. After one is familiar with these holes, one can tell them by the segregation of silicon in them, especially on the edge.

Such a hole occurs very often between two cores. It is of a conical shape, going down—very much as when the silicon first starts to show up on a test on almost any furnace where the metal starts to take up the silica, forming silicon in the metal.

An analysis can be obtained by taking small drillings from around the hole. For instance, if a hole is ¼ inch in diameter at the top, going down to probably 1/16 inch at the bottom, use a drill a bit larger (say, 5/16 inch) and drill down a certain distance, then use a drill a bit smaller, and so on. The idea is to examine the metal around that blow hole.

My experience has been that a steel casting which would run in the neighborhood of 0.3 in silicon, will show up anywhere from 0.45 to 0.55 around the hole. I have found many which ran much higher, according to the temperature and the kind of core used.

Mr. Batty, have you had any experience with this problem?

GEO. BATTY: When I was answering Mr. Jones' question it was specifically on pin holes, not blow holes. Admittedly, pin holes are "blows," but they are a distinct type and require separate discussion.

This raises an interesting point which I have discussed with Major Bull. There is a looseness in our foundry terms which needs ironing out. I was discussing pin holes, or the product of injected gases, and not blow holes. Blow holes introduce another subject, usually considered as being incidental to imperfectly reduced metal.

I said that it does not matter what shape the pin hole is—meaning, whether of the blunt pear shape, or the very elongated pear shape, or whether the pin hole is visible from the outside of the casting, or whether the mouth of the pin hole is revealed only after annealing and is removed with the annealing scale. Bear in mind that I was not discussing blow holes due to imperfectly reduced steel, but rather, the point raised by Mr. Jones as to the shape of pin holes.

I reaffirm that it makes no difference what shape the pin holes are—our business is to prevent their formation.

In regard to what Mr. Mooney calls silicon holes, I have not yet come across them under such identification. I should be interested in

*Falk Corporation, Milwaukee.

having what data he possesses on the subject. Obviously, the excess silicon in the metal, forming the surface of the cavity, is very interesting in that it is associated with a low carbon—lower carbon than in the surrounding metal.

REPLY BY AUTHOR

GEO. BATTY: Mr. Melmoth is likely to create some misapprehension in the minds of those who heard the discussion, or who read the proceedings, when he states that most of the initial thought on a certain subject was done by me. As a matter of fact Mr. Melmoth had performed a great deal of work on the reclaiming of sand before I made any real contact with the steel castings industry, and it was from him that I learned the significance of fines in re-used molding sand.

The point to which he really refers is purely an incidental one and concerns my suggestion that the condensate film may be an important factor. The condensate film is dangerous only in so far as it occurs in a mold of unsuitable permeability, or in a mold having an excessive moisture content.

I believe we are in agreement, however, in the matter of the extent of reclaiming operations, and I personally must disagree when Mr. Pugh infers that all the fine material must be taken from a molding sand in order to make it safe for re-use. A further point of disagreement is that I do not consider sand grains of between 60 and 100 mesh as undesirable, unless the remainder of the sand is of a considerably coarser grade. Even here the proportion of the material that Mr. Pugh referred to as "border-line material" is a factor which must be considered, and we may not safely say that such material is dangerous unless we are creating an unnecessarily artificial standard of a grain size.

Mr. Pugh may be partly right if his reclaimed sand is bonded with fireclay, which, of itself, is comparatively weak bond. In foundries which operate green sand and use bentonite and cereal binder as their binding media, it is unnecessary, wasteful, uninformed and uninspired to remove the whole of the fine material.

Bentonite and cereal binder are exceedingly strong and will admit of considerable dilution by fines or by silica flour to produce a thoroughly satisfactory molding medium. The really dangerous portion of the fines in a used sand which is to be reclaimed is iron oxide. This was brought out very trenchantly by Mr. Dierker in his recent paper.

In order that no less than justice may be done to Mr. Pugh, it must be stated that a number of foundries with which the writer is associated are using a sand of considerably finer grain size than that predicated by Mr. Pugh as being desirable. With such a fine-grain sand we do not attempt to remove the whole of the fines but have approximately four per cent of material which passes the 100 mesh present in our reclaimed sand as it goes to the mill for the addition of bentonite, cereal binder and water.

Our reclaiming system appears to give us satisfactorily the essential elimination of the oxide of iron which Mr. Dierker established as being

so dangerous. We find it desirable to have a diluent of the strong bonds which we use in the preparation of green sand, and we therefore adjust the reclaiming system to give us a controlled amount of non-deleterious fine material to act as a diluent. If we removed all the dust, we should be compelled to use silica flour as a diluent in order to produce the constitution which we consider desirable.

With reference to Major Bull's illustration of the relative effect of coarse and fine mold surfaces, while I am partly in agreement with him, I cannot agree that identical conditions pertain over the whole of the surfaces which are mold-metal interface. Near the gates the mold is very considerably heated by the passage of hot metal and, on a coarse-surfaced mold, there may be some considerable burning on of the sand—similar to that indicated, at Washington, by Dr. Moldenke when discussing iron castings. But at parts of the mold relatively remote from the gates, I consider that the quench effect of the mold will increase as the fineness of the mold surface increases.

As metal flows through a mold, some of its heat is absorbed by the mold and by mold gases, and the metal is rapidly losing temperature and fluidity. It is losing, therefore, its ability to conform closely to the inequalities of the mold surface, and if it does not contact intimately with the mold there must be small pockets of atmosphere between the metal face and the mold face at the depressions in the mold face. Hence, the heat absorption by the mold is likely to be less in a coarse-surfaced mold than in a fine-surfaced mold.

Considering a number of the fundamentals, I believe the fine-surfaced mold is to be preferred against the coarser sand, because there is less tendency to adhesion near the gates and there is a greater contact of metal with mold, hence a greater heat absorption by mold from metal, which predicates more rapid solidification and more perfect functioning of properly disposed feed heads.

It is within my experience that a coarse-grained sand of good reported permeability has given blows or caused pin holes at re-entrant angles of the mold, and that such troubles have disappeared when a finer sand of much lower permeability, but of identical moisture content, has been used with metal of apparently the same temperature. Such blows might possibly be explained, in the case of the coarse-grained sand, by postulating entrapping of a little air in the valleys between the mountains of the mold surface.

It is conceivable that a sand is not uniformly permeable and, on a mold face which, under conditions of normal sampling for permeability tests, would give a high permeability reading, there may be valleys in the mold face that have no outlet or no connection with any one of the pores of the sand.

This proposition may seem a little extravagant to some; but, although it is not urged as a probability, it still seems a possibility and is therefore worthy of consideration. Such consideration has led a number of us to the consistent use of a much finer grade of sand than was formerly employed.

Blistering Tendency of Some Cast Irons When Enameled*

By A. I. Krynitsky** and W. N. Harrison,† Washington

Abstract

The blistering of enamels on cast-iron ware has been a prolific source of trouble, several theories having been advanced to account for it. Gas entrapped in the enamel obviously is the cause, but what causes the generation of the gas has been a disputed point. An investigation of this subject was undertaken and pig irons of various types were melted and the castings poured and enameled. Data accumulated led to several conclusions, the more important being: (1) Physical defects, especially sponginess, will give rise to blisters. (2) An enamel may be composed, prepared or applied in such a manner as to cause blisters, irrespective of the character of the iron used. (3) The gases forming blisters are CO and CO_2. (4) Blistering is quite often due to causes originating in a very thin surface skin called a "micro chill"; the tendency of the cementite of this skin is to break down during the enameling process to very finely divided "temper carbon," which is more readily oxidized than massive graphite or cementite; this breaking down leads to the formation and evolution of CO and CO_2, which causes greater or less damage according to the stage of the enameling process at which it occurs. (5) There are probably two kinds of non-blistering iron, one with a very small per cent of combined carbon in the surface layer and the other in which cementite is so stable that it takes a relatively long time to break down into ferrite and temper carbon. (6) During the early stages of enameling, both blistering and non-blistering irons evolve gas, which is attributed to quick oxidation of submicroscopic graphite and which escapes before the enamel has fused to a retentive condition. (7) Addition of graphitizing agents, such as silicon, may be beneficial, but it is harder to prevent the micro-chill than the ordinary or macro-chill. (8) Removal of the surface layer by deep sand blasting or "burning out" appears to be the most practical remedy for blistering of sound castings.

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INTRODUCTION

1. In the application of vitreous enamel to cast iron, as in the manufacture of household ranges, bath tubs, etc., "blisters" may form in the enamel. Blistered enamel ware is rough, unsightly and often unserviceable.

Enameling Processes

2. The enameling process may be carried out in several ways, depending on the type of enamel used. In the so-called dry process, a suspension of enamel is sprayed or painted on a cold casting and dried, after which the coated casting is heated until this first or "ground" coat is matured. A dry second or "cover" coat is then sifted onto the hot ground coat and the piece at once reheated to mature the cover coat.

3. The wet process is similar to the dry process in the application of a ground coat, but the piece is then cooled and the cover coat applied in the same way as the ground coat. This is the process with which the present investigation is primarily concerned, because it is believed to furnish a better criterion of blistering tendencies than the dry process. In the two-coat processes the ground coat is more infusible than the cover coat, and in firing a higher temperature is used.

4. In the so-called single-coat (wet) process the same enamel is used in the first coat as in any subsequent coat or coats, but the first coat receives a somewhat more severe firing treatment. Such single-coat enamels are usually more fusible than the two-coat wet-process enamels, often being high in lead oxide in order to produce this fusibility. The firing is done at much lower temperatures than in the other processes.

Blisters and Gas Evolution

5. It is obvious that blisters are caused by gas entrapped in the enamel. Craters are evidence of the previous presence of temporary blisters, the enamel not closing completely after the escape of the gas. Slight "dimples" will result when the enamel closes but does not become quite level; if the enamel does become level, obviously no harm is done through the previous existence of the bubble.

6. Hence, it is not gas evolution in itself that is to be feared, but gas evolution at the wrong time. The more fluid and fusible the enamel, the less likely it is to entrap bubbles or to leave a crater after a bubble breaks.

Effect of Variations in Usual Enameling Practice

7. The firing is a rather delicately balanced operation which is affected by changes in the rate at which heat is taken up by the load (as with loads of different weight or different weight-area ratio), or in the rate at which heat is supplied to the furnace.

8. Both time and temperature play a part in the maturing of an enamel. Firing a cover coat for a very brief period in a furnace at high temperature may give equally satisfactory results as firing for a longer time at a lower temperature. However, slight changes in the firing period produce much greater differences in the results in the first case than in the second.

9. In order to get reproducible results indicating the tendency of a given iron to blister, it is found necessary to avoid too rapid a rate of heating.

10. Whatever the source of the gas responsible for blisters in enamel coats, if it is evolved before the enamel starts to fuse it is not retained in the enamel. If it is evolved while the enamel is semi-fluid and very viscous (under-fired), it may be retained. If evolved when the enamel is fluid, it may do no harm unless it is evolved so slowly that it is not released before the enameled article is removed from the furnace. It is quite possible that a non-blistering iron might give off more gas, but give it off more readily and more nearly at one temperature, than a blistering iron.

11. If firing is carried on so long, or at so high a temperature, that reactions between enamel or air and metal take place (which either do not occur or occur with only slight intensity at lower temperatures or with shorter firing periods), blisters may occur from over-firing. A combination of a metal and an enameling procedure that allows a wide range of firing conditions without blisters is much to be desired.

Ideas on Blistering Expressed by Enamelers

12. Northern pig iron is said to produce castings which show a greater tendency to the blistering phenomenon than castings from Southern pig iron, even though the castings may have closely similar chemical composition. Not all Northern irons give trouble from blisters, and blistering of Southern iron is sometimes encountered.

13. The outstanding difference between Northern and

Southern pig irons as classes is the higher phosphorus content and consequent greater fluidity of the Southern iron.

14. Remelting of Northern pig, or the admixture of 30 to 50 per cent of Southern pig iron, scrap, or remelted Northern pig iron with 50 to 70 per cent of virgin Northern pig iron, is said to reduce the tendency toward blistering. This allegation has not been definitely proved.

15. A British visitor stated that similar troubles in British practice were avoided by ceasing to use pig iron from certain blast furnaces. It is stated that pig iron from slow-driven blast furnaces is considered to give fewer enameling defects, including blisters, than that from rapidly driven furnaces.

16. Pig iron with high manganese content is said to cause blisters. Excessively high sulphur content also is asserted to cause blisters and pinholes.

17. White iron castings for malleableizing are said to cause blisters unless properly "annealed." Gray-cast-iron plates chilled on one side only are said to show a greater tendency to blistering on the chilled side. On the other hand, a white chilled layer on gray iron for enameling purposes has been advocated.

18. It has been stated[1] that low-silicon iron, low in graphite, gives less trouble from blisters than does high-silicon iron, and the effect of graphite has been ascribed to its reaction with metallic oxides of the enamel with the formation of carbon monoxide or dioxide gas. It was further stated that the higher the phosphorus content of the iron, the lower the silicon can be. Hence, indirectly, high phosphorus tends to prevent blisters.

19. On the other hand it has been stated[2] that low combined carbon—i.e., high graphitic carbon—favors freedom from blisters, and that high combined carbon produces the opposite results.

20. A casting which has blistered on the first attempt to enamel it, if cleaned from enamel by sand blasting, may ordinarily be re-enameled without further trouble from blistering. Heating the castings to redness in the air (so-called annealing or burning-out) before sand-blasting is the generally accepted preventive of blistering. It is generally thought of either as driving out contained gases or as removing carbonaceous matter

[1] Staley, H. F., *Materials and Methods Used in the Manufacture of Enameled Cast-Iron Ware*, Bureau of Standards Tech. Paper No. 142, p. 140, 1919.

[2] Malinovsky, A., *Enameling Defects Due to the Cast Iron*, Jour. Amer. Ceramic Soc., 8, p. 72, 1925.

from the surface, whether this be graphite of the iron itself or carbon from a carbonaceous mold facing.

EXPERIMENTAL TESTS

21. In preliminary work, two lots of Northern pig iron were studied: R_1 (3.62 per cent Total C, 3.06 Graphitic C, 0.56 Combined C, 0.78 Mn, 0.83 P, 0.029 S, 2.99 Si), having only a very slight tendency to blister; and L_1 (3.81 per cent Total C, 3.15 Graphitic C, 0.66 Combined C, 0.67 Mn, 0.46 P, 0.045 S, 2.31 Si), being strongly blistering.

22. By using the same ground and cover coats of enamel in the wet process, and firing each coat for a definite time and at a definite temperature, it was found that remelting did not noticeably decrease the tendency of L_1 to blister. In this work the castings were cleaned by sand blasting, but the depth of the surface layer removed by sand blasting was not controlled.

23. A supply of castings which had been used at the Bureau in previous work on enameling, and which did not blister, was remelted in the electric furnace and cast into test plates. The remelted samples blistered badly.

24. This made it evident either that the method of making the enameling test contained some uncontrolled variable, or that blistering was the result of some variable in a given heat rather than in a given lot of cast iron.

25. The "range" method of firing the enamel—in which the ground coat was fired upon seven specimens for periods varying from 3 to 17½ minutes—was then adopted and found to differentiate much better between lots relatively free from blistering and those having a tendency to blister, than did firing the specimens for only one length of time. A weakly blistering iron could be fired with about the same result at three or four different lengths of time. A strongly blistering iron would generally show some one length of firing at which it was relatively blister-free, but the optimum time varied in different lots and heats.

26. With this improved method of attack it was possible to get a better idea of the effect of the variables involved.

27. Two more irons, a weakly blistering (R_2) and a strongly blistering (L_2) were studied. Four heats of each of these, containing over 700 specimens, were made up and tested at the Bureau and in two industrial laboratories. The compositions are given in Table 1.

Table 1

COMPARISON OF COMPOSITIONS OF IRONS BLISTERING BADLY (L_2) AND BLISTERING WEAKLY (R_2)

Heat No.	Iron	Approx. pouring temps. degs. C.	Composition, Per Cent								Avge. Grading
			Total C	Graph. C	Comb. C	Mn	P	S	Si	Cr	
1-55	L_2	1410-1388	3.40	2.93	0.47	0.72	0.555	0.035	2.37	0.04	4.8
2-55	L_2	1380	3.54	3.06	0.48	...	....	....	2.34	...	4.5
3-55	L_2	1390	3.46	2.94	0.52	...	....	....	2.39	...	4.0
4-55	L_2	1400	3.36	3.10	0.26	0.72	0.515	0.039	2.30	0.04	3.1
1-56	R_2	1398	3.13	2.94	0.19	...	....	....	2.53	...	3.9
2-56	R_2	1398	3.48	3.10	0.38	0.61	0.790	0.027	2.22	0.03	2.4
3-56	R_2	1388	3.39	3.11	0.28	...	....	....	2.51	...	2.4
4-56	R_2	1380-1350	3.45	3.08	0.37	...	....	....	2.45	0.04	3.7

28. The "average grading" (see Table 1) refers to an arbitrary system of rating with 1 as excellent and 5 as extremely badly blistered. While there were variations in the results, it is clear from the averages, and even more clear from inspection of the specimens, that heat 4-55 of iron L_2 was better than two of the heats of the weakly blistering iron.

29. This heat had the lowest combined carbon of its group (L_2), but with R_2 this relationship between the combined carbon and the tendency toward blistering did not hold. Idiosyncrasies in the respective heats, rather independent of composition, were again shown.

Removal of the Surface Layer

30. Attention was then directed to the condition of the surface layer. Fig. 1 shows plates of irons R_2 and L_2, half of each plate being machined off before enameling. Regardless of whether the lightly sand-blasted surface (lower part of the specimens, Fig. 1) blistered or not, the machined surface was free from blisters.

31. This showed very definitely that the blistering trouble lies in the surface layer.

32. Pickling deeply enough to remove the surface layer, or deep sand-blasting, had the same beneficial effect. That the layer which needs to be removed is very thin was shown by machining the surface of some slightly warped plates (Fig. 2). The sharpness of the boundary of the blistered area shows how infinitesimal a layer need be removed.

33. These experiments effectually disposed of the supposition that the blistering was due to gas adsorbed in the body of

the casting, and indicated that it was not the differences in composition nor in the structure of the body of the casting—but rather the nature of a very thin surface layer—that was responsible for blistering.

34. It is not remarkable that metallurgists have not heretofore studied this extremely thin surface layer, since its existence would have no effect on the suitability of cast iron for most uses. Only in such uses as involve the coating of the surface—as in enameled, tinned and galvanized products—would the thin skin have any effect on the quality of the product, or its existence be noted. The problem is, then, peculiarly one of the enameling process.

35. Whereas previous study had been directed primarily at the chemical composition and physical soundness, the work at this point became concentrated on the surface layers of the castings.

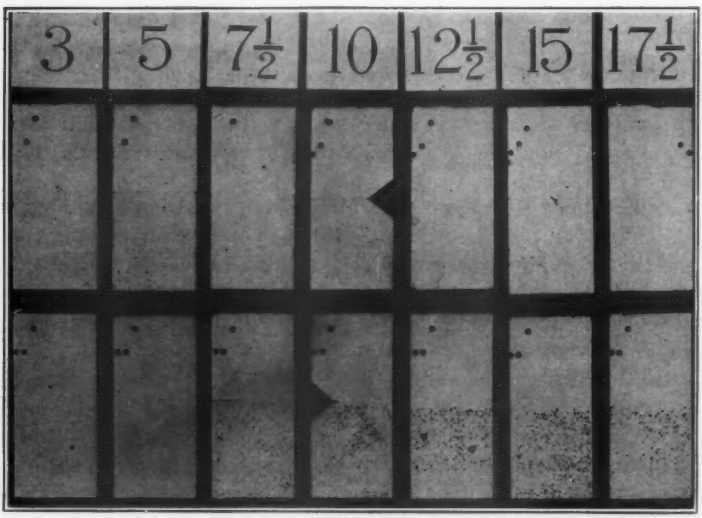

FIG. 1—EFFECT OF MACHINING-OFF ORIGINAL IRON SURFACE. SURFACES OF ENDS OF PLATES BEARING IDENTIFICATION HOLES MACHINED OFF BEFORE ENAMELING. TOP ROW, IRON R_2; BOTTOM ROW, IRON L_2. NUMBERS INDICATE MINUTES OF FIRING GROUND COAT AT 875 DEGS. CENT. (1605 DEGS. FAHR); ALL COVER COATS, 8 MINUTES AT 800 DEGS. CENT. (1470 DEGS. FAHR.).

36. A more vigorously controlled sand-blasting procedure was used in the subsequent work, to minimize any irregularities in results arising from variations in sand-blast treatment. Ottawa silica sand (20-30 mesh) was delivered at 60-lb pressure, from a nozzle of 1-in. inside diameter, normal to the surface of the specimens placed 4 inches below for a period of 45 seconds. The specimens were moved horizontally during sand blasting, and when an occasional specimen having less than the usual 18-sq.-in. surface was blasted, a proportionally shorter period of blasting was used.

Additions of Softening Agents, also Phosphorus and Fused Sodium Carbonate

37. On the theory that a softer (lower combined carbon) iron might be less blistering and more susceptible to removal of the surface layer in an ordinary cleaning process, an attempt was made to improve iron L_2 (the more strongly blistering one) by softening it. Since an increase in the silicon or nickel contents would tend to produce this result, one-half per cent of each element was added separately and the "range" method of enameling test applied.

38. While no conclusive results were obtained in a limited

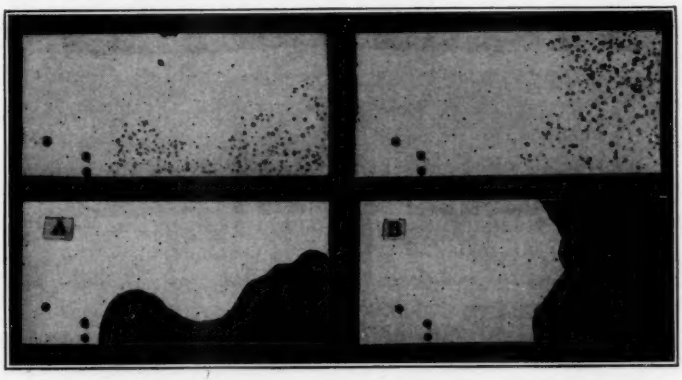

FIG. 2—PLATES MACHINED OFF AT SLIGHT ANGLE BEFORE ENAMELING. IRON L_2. HEATS 2-55 AND 3-55. LETTERED PLATES ARE GRAPHICAL REPRESENTATIONS OF APPEARANCE OF PLATES AFTER MACHINING. UNSHADED PORTIONS MACHINED; SHADED PORTIONS HAD NORMAL SAND-BLASTED SURFACES. GROUND COAT FIRED 10 MINUTES AT 875 DEGS. CENT. (1605 DEGS. FAHR.); COVER COAT, 8 MINUTES AT 800 DEGS. CENT. (1470 DEGS. FAHR.).

number of experiments with ladle additions of one-half and two per cent nickel, nor with 1 per cent aluminum, promising results were obtained with silicon additions made in the furnace.

39. Fig. 3 shows that there was a noticeable improvement in the enameling properties of the blistering iron, L_2, with a higher silicon content, addition of this element being made in the furnace. While the variation in the silicon content was evidently not sufficient to cause a marked change in the average amount of combined carbon throughout the cross-section of the castings, it is thought that this variation was large enough to affect the combined carbon present in the surface layer.

40. The phosphorus as well as the silicon contents of the strongly blistering iron L_2 were increased in certain heats to correspond with the weakly blistering iron R_2. Also, a few tests were carried out using fused sodium carbonate as a fluxing addition, but the results of all these experiments did not indicate any marked improvement.

Study of Burned-in Molding Sand

41. There appeared to be a possibility that the condition responsible for blistering might be a layer of burned-in sand grains which had not been removed by sand blasting, although it seemed likely that such material would be inert.

42. Hence, specimens of non-blistering iron were deeply sand blasted at one end and the amount of sand blasting was decreased sharply toward the other end, where burned-in sand grains could be detected readily with a binocular microscope. These burned-in sand grains did not produce any blisters when the specimens were enameled.

43. In another test, molding sand was scattered over a deeply sand-blasted specimen and the enamel applied as usual. This specimen did not blister. Hence, adhering sand in itself does not appear to be a direct cause of blistering, although a burned-in layer would retard the removal of the outside layer of metal during sand blasting.

44. Striking confirmatory evidence of this was obtained from a plate of blistering iron L_2 which had a firmly adhering scale of burned-in sand. This plate was sand blasted while held at an angle to the sand stream so that one end was sand blasted just enough to be visibly free from adhering sand but not enough to remove the "micro-chilled layer." The blasting was progres-

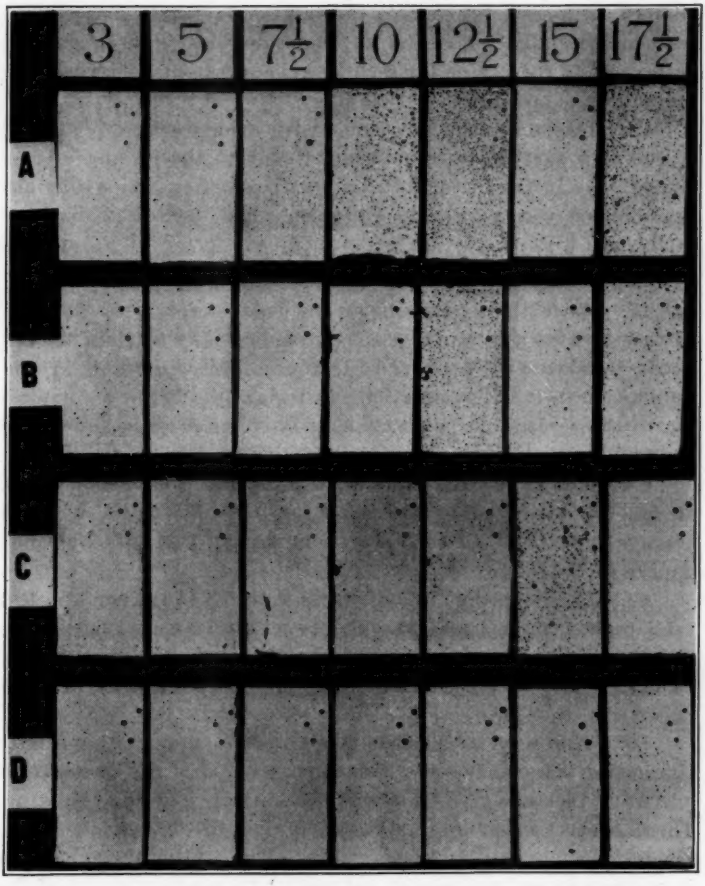

FIG. 3—EFFECT OF SILICON ADDITIONS ON BLISTERING TENDENCY. SILICON CONTENT: A, 2.32 PER CENT; B, 2.51; C, 2.65; D, 2.92. AVERAGE OF TWO DETERMINATIONS. NUMBERS INDICATE MINUTES OF FIRING GROUND COAT AT 875 DEGS. CENT. (1605 DEGS. FAHR.); ALL COVER COATS, 8 MINUTES AT 800 DEGS. CENT. (1470 DEGS. FAHR.).

sively decreased as the other end was approached. A strip at the end was completely shielded from the blast.

45. On enameling, the shielded strip was entirely free from blisters, although, of course, the adhesion of the enamel was not commercially satisfactory. The sand-blasted area showed progressively increasing blistering as the metal surface was more completely exposed.

46. This test also gave conclusive evidence that blistering is due to a surface reaction and not due to the freeing of "occluded" gas in the metal itself, since the portion which was not sand-blasted was as free to evolve such gas as that which was sand-blasted.

Composition of Surface Layers

47. Since the surface layer involved is very thin and the surface of a casting is not perfectly smooth, any attempt to mill off the outside layer for chemical examination will result in contamination of it with underlying material. However, a comparison of the results of chemical analysis of the surface and of the body of the casting would appear to give useful indications.

48. Heat 2-55 of iron L_2 with an average blistering index of 4.5, i.e., badly blistering, and heat 3-56 of iron R_2 with an average index of 2.4, were thus compared. The data obtained appear in Table 2.

49. It is seen that in both cases there is, at the surface, less total carbon, manganese, phosphorus and silicon, but more combined carbon and sulphur. That is, the surface skin seems to be higher in iron than the interior, which segregation is to be expected.

50. The increase in combined carbon appears especially significant since that will obviously accompany the presence of a hard surface layer, which is difficult to remove by sand blasting. There seems, therefore, to be a "micro-chilled" surface layer ("micro" refers here to the thickness of the chilled layer) which is apparently not necessarily controlled by the propensity of the iron to chill—in the ordinary sense of giving a visibly thick layer of white iron on rapid cooling—and which may be different in its nature from an ordinary chilled layer.

Microscopic Examination of "Micro-chilled" Layer

51. The difference in composition at the extreme surface is probably greater than is shown by the chemical analysis, since

in machining off the surface layer, thin as it was, some material more nearly approaching the body of the casting in composition undoubtedly was included. The micro-structure of the surface of iron R_2, heat 3-56, indicated that it contained much less combined carbon than the surface of iron L_2, heat 2-55. The surface of the best heat (4-55) of iron L_2 appears to be more completely broken up into ferrite and graphite than is the case of heat 2-55.

Effect of Nitrogen

52. The fact that the nitrogen content (Table 2) of the thin surface layer is higher than that of the interior, calls for attention, especially as the strongly blistering iron shows double the amount of nitrogen in the surface that the weakly blistering iron does.

53. The nitrogen might play a part in two different ways. If it is present as iron nitride, which decomposes at or below enameling temperatures, it constitutes a possible source of gas bubbles. If, on the other hand, it is present as chromium or titanium nitrides, these might decompose slightly at enameling temperatures; but the greater part of the nitrogen would be retained and would tend to form a hard skin, as in the case of

Table 2

CHEMICAL COMPOSITION OF SURFACE LAYER AND INTERIOR OF CAST PLATES OF IRONS L_2 (BLISTERING BADLY) AND R_2 (BLISTERING WEAKLY)

	L_2 Heat No. 2-55 (badly blistering)		R_2 Heat No. 3-56 (weakly blistering)	
Elements	Outside layer 0.003 in. thick	Comparison layer (0.01 in. thick), several hundredths in. beneath surface	Outside layer 0.003 in. thick	Comparison layer (0.01 in. thick), several hundredths in. beneath surface
Total C	2.71	3.54	2.84	3.31
Comb. C	0.45	0.34	0.42	0.27
Graph. C	2.26	3.20	2.42	3.04
Manganese	0.61	0.73	0.45	0.61
Phosphorus	0.435	0.500	0.605	0.835
Sulphur	0.044	0.037	0.031	0.022
Silicon	2.42	2.63	2.33	2.46
Nitrogen	0.0033	less than 0.0005	0.0015	less than 0.0005
Total	6.22	7.44	6.26	7.24
Iron by difference	93.78	92.56	93.74	92.76

special steels containing aluminum and chromium, heated in an atmosphere of ammonia.

54. That nitrides probably play no direct part in the formation of blisters was indicated by the following test:

55. Half of the drag side of $6x\frac{3}{4}x\frac{3}{16}$ in. strips of R_2 iron, heat 3-56, were lightly machined and both drag and cope sides were given the standard sand blasting. These strips then were heated to 500 degs. Cent. (930 degs. Fahr.) in a stream of ammonia for periods of one, two and five hours, according to the usual method employed in forming nitride coatings. The nitrided strips were then very lightly sand blasted and the cope side of each strip was machined off to give a sample for chemical analyses for nitrogen, the layer removed being 0.003 in. thick.

56. Analysis showed the nitrogen content of the surface layer of the three to be 0.05, 0.08 and 1.0 per cent, respectively. On enameling these specimens on the drag side, in the usual fashion, there was no sign of blisters either on the machined area or on the non-machined area, although both contained nitrogen in far higher proportions than that found on the surface layer of the blistering iron.

57. That it is comparatively easy to produce a nitride skin on ordinary cast iron is probably not well known, but cast iron is said to have been commercially nitrided.

58. There is some evidence that the minute amount of nitrogen introduced in melting steel, and presumably in cast iron, may be more stable than the nitride formed on the surface by heating in ammonia gas; hence, it might decompose at a different temperature, perhaps just a temperature at which the gas would be caught in the enamel. The test, therefore, may not entirely exclude the possibility that nitrogen causes blistering.

Spectroscopic Examination

59. There is a possibility that traces of elements that would form hard nitrides might play a part in the formation of a hard skin. Spectroscopic analysis of the strongly blistering iron L_1, and the weakly blistering iron R_1, made early in the investigation, showed nickel to be absent, but that titanium, vanadium, chromium and traces of aluminum and, of course, copper were present in addition to the elements usually reported in chemical analyses of cast iron.

60. Chemical analyses for these elements, and for total oxygen and hydrogen, gave the results shown in Table 3.

Table 3

CHEMICAL ANALYSIS OF BADLY BLISTERING IRON (L_1) AND WEAKLY BLISTERING IRON (R_1)

Designation of irons	Character	Composition, Per Cent						
		Cu	Ti	Cr	V	Al	O	H
L_1	Strongly blistering	0.07	0.08	0.025	0.030	*	0.002	0.0007
R_1	Weakly blistering	0.03	0.15	0.010	0.025	*	0.004	0.0005

*Less than 0.005 per cent.

61. Since copper is present in all pig iron and is not a carbide or nitride forming element, it can hardly be suspected of having anything to do with blistering. Vanadium and aluminum are essentially identical in the two irons. Titanium, a nitride-forming element, might be suspected; but the fact that the strongly blistering iron contains only half as much as the weakly blistering one, seems to remove titanium from suspicion.

Effect of Chromium

62. Chromium was present in the strongly blistering iron L_1 in appreciably larger amounts than in the weakly blistering R_1. Since small amounts of chromium are known to increase the chill on cast iron and to interfere considerably with the malleableizing anneal of malleable cast iron, by tending to retain the carbon in the combined form, there is a possibility that even this slight difference in chromium content might favor the formation or retention of a surface layer higher in combined carbon, hence harder and more difficult to remove in sand blasting.

63. To examine further the hypothesis that the chromium content might have a connection with the propensity toward blistering, the irons used in the latter part of the investigation were analyzed for chromium, with the results shown in Table 4.

64. It will be noted that the strongly blistering iron L_2 and the worse heat (4-56) of the weakly blistering iron R_2 contain slightly more chromium than the better heat (2-56) of R_2. While the difference is very slight, it is in the direction of damage due to chromium.

65. Although the enamel rating obtained with Southern iron is not comparable to the other ratings, there is little doubt

Table 4

PER CENT OF CHROMIUM IN BADLY BLISTERING (L_2), WEAKLY BLISTERING (R_2) AND SOUTHERN IRONS

Iron	Heat No.	Chromium, per cent	Enamel rating
L_2	1-55	0.04	4.8
L_2	4-55	0.04	3.1
R_2	4-56	0.04	3.7
R_2	2-56	0.03	2.4
Southern charcoal	42	0.03	*
Southern	41	0.10	*

*Ratings not comparable since irons were tested only at the Bureau.

that it has as little blistering tendency as any iron studied. Yet it contains much more chromium than any of the others, so that the mere presence of chromium cannot be taken as the sole cause for blistering.

66. This cannot be regarded as entirely eliminating chromium from consideration, because the formation of the micro-chilled layer is very evidently a matter of delicate balance, and the effect of chromium in irons of different composition as to other elements may not be the same.

67. In order to study the chromium problem more thoroughly, an experiment was made to see whether addition of chromium to the weakly blistering Northern iron R_2 increased its propensity to blister. A noticeable increase in blistering accompanied the addition of 0.03 per cent chromium, but the larger additions (0.05 and 0.10 per cent) showed no effect.

68. Similar experiments were carried out with additions of chromium on the blistering iron L_2 with the purpose of stabilizing combined carbon of the surface layer of those castings. Chromium in the quantities used had practically no effect.

Gases and Gas-Forming Elements

Oxygen

69. In the work by Herty and Gaines[3] of the U. S. Bureau of Mines, it has been found that pig iron tapped after a blast furnace "slip" may contain an excessive amount of suspended silica or silicates in a very fine state of subdivision, and that these, being difficult to reduce or flux out in steel making, give inferior steel.

[3] Herty, C. H., Jr., and Gaines, J. M., Jr., *Study of Unreduced Oxides in Pig Iron*, Tech. Publ. No. 165, Am. Inst. Min. & Met. Eng.

70. It does not appear likely, however, that the presence or absence of such inclusions is directly responsible for the difference between blistering and non-blistering irons. If the suspended particles are not reduced by the carbon of the iron while it is molten, it is not likely that they will be reduced by it in the solid metal when heated only to enameling temperatures.

71. Hence, the evolution of CO from within the metal itself, by reaction of inclusions during enameling, is not a plausible explanation of blisters. However, the vacuum fusion method for total oxygen determines the oxygen of silica and silicates, and hence will reflect the amount of inclusions present.

72. As shown in Table 3, however, very little difference was found in the oxygen content of the two irons, the blistering iron containing even slightly less oxygen than the weakly blistering one.

Hyrogen

73. The difference in the hydrogen content of the two irons is within the precision of the analytical method, and since the amounts are so nearly the same, no indication is given that hydrogen is a factor.

Sulphur

74. There is also a possibility that the gas might come from the oxidation of manganese sulphide or iron sulphide at the surface of the metal. It is known that sulphur or sulphates in the enamel itself will cause blisters.

75. To examine this hypothesis, sulphur determinations were made on the surface layer (0.003 in. thick) milled off of specimens of the strongly blistering iron L_2, heat 2-55, after the usual sand blasting, and of other specimens of the same heat that had been put through the heating cycles of the enameling process under oxidizing conditions but without enamel.

76. These cycles consisted of heating in air 12½ minutes at 875 degs. Cent. (1605 degs. Fahr.), cooling in air and again heating in air 8 minutes at 800 degs. Cent. (1470 degs. Fahr.). The amount of sulphur was not changed, being 0.050 per cent in each case, and this indicated that there is no preferential oxidation of sulphur and that the blister-forming gas is probably not SO_2.

Gas in Blisters

77. If the composition of the gas in the blisters could be determined, one would have a very useful clue as to their source. On piercing the blisters of an enameled specimen under water, and collecting and analyzing the gas, it was found to be air.

78. Microscopic examination of the cross-sections of enamel coatings (Fig. 4) indicated that many of the internal bubbles were connected by channels with each other and frequently with the air, so that whatever the original gas they contained during the process of blistering, it may have escaped and have been

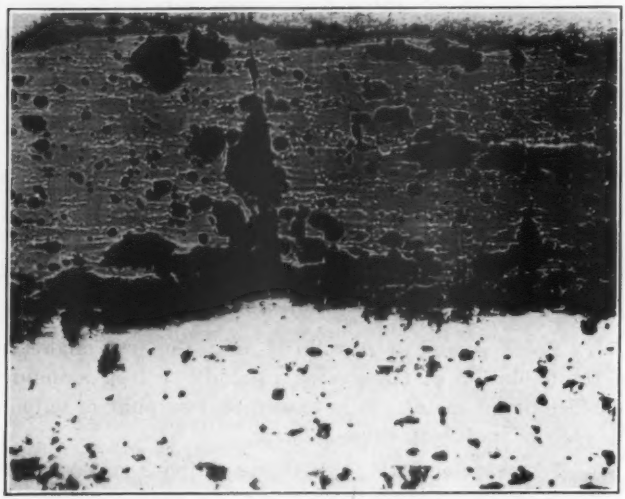

FIG. 4—CROSS-SECTION OF ENAMEL AND SURFACE LAYER OF IRON. SOUTHERN IRON, HEAT 41. POLISHED, 100X. NOTE INTER-CONNECTED CHANNELS IN ENAMEL. NO BLISTERS OBSERVED ON THIS SPECIMEN. GROUND COAT FIRED 10 MINUTES AT 875 DEGS. CENT. (1605 DEGS. FAHR.); COVER COAT, 8 MINUTES AT 800 DEGS. CENT. (1470 DEGS. FAHR.).

replaced by air. Hence, it was necessary to collect the gas formed in the act of blistering.

79. By a series of tests (too long to describe here but given in detail in the full paper) it was shown that the blister-forming gas is a mixture of CO and CO_2, which will hereafter be referred to as CO_2. A minute amount of this comes from the enamel

itself, but this is negligible in comparison to that coming from oxidation of the surface of the iron.

80. On heating the uncoated iron in air and collecting the gas, it was found that in different heats from the same iron, varying in blistering tendency, the ones that blistered the most produced the most CO_2, but that other non-blistering irons gave off more CO_2 than some of those that blistered badly. The appearance of the oxidized surface, however, varied regularly from smooth and velvety in the non-blistering irons, to rough in those that blistered the most.

81. Firing the ground coat on the irons in an atmosphere of nitrogen and collecting the CO_2, gave less CO_2 than on firing in air; and the amounts were about the same, regardless of the type of iron. The oxygen for this reaction probably came from air in the ground coat and adsorbed on the metal surface.

Table 5

CO_2 GAS FORMED IN FIRING OF GROUND-COAT AND COVER-COAT ENAMELS ON BADLY BLISTERING (L_2), WEAKLY BLISTERING (R_2) AND SOUTHERN IRONS

		Equiv. CO_2		
Iron	Heat	During ground-coat firing, grams.	During cover-coat firing, grams.	Total
L_2	1-55	0.012	0.003	0.015
L_2	2-55	0.011	0.004	0.015
L_2	4-55	0.009	0.004	0.013
R_2	2-56	0.010	0.005	0.015
Southern	41	0.011	0.004	0.015

82. The appearance of the enameled specimens was analogous to that of the specimens heated in air. The non-blistering irons and the machined edges of all the specimens were smoothly coated, while the coats on the blistering irons were rough.

83. Enameling in air and collecting the CO_2 gave no clear difference in absolute amount of CO_2 from different irons, the amounts collected under the conditions of the test ranging from 0.009 to 0.012 grams. On the basis of the amount of CO_2 formed, the irons arranged themselves in the same order as they did on heating in air, but this was not the order of their propensity toward blistering.

84. On burning the cover coat over the ground coat, additional CO_2 was formed in amounts ranging from 0.003 to 0.005 grams. If we consider the total CO_2 (or rather, the CO plus CO_2, calculated to the CO_2 equivalent), we see that the total amount

evolved from samples during the firing of ground-coat and cover-coat enamels varies but little.

Rate of Carbon Oxidation

85. The data obtained in all of the preceding tests indicate that carbon oxidized from the surface of the iron specimens is the chief source of the gas evolved during the firing of ground-coat enamels on cast iron. There is little or no evidence that either moisture or the oxide constituents of the enamel take an appreciable part in this oxidation of carbon from the surface of the iron. Oxygen of the air present in the enameling furnace is the oxidizing agent.

86. The foregoing experiments on gas evolution have been in reference only to the total amount of gas evolved during the firing period. It is apparent, however, that any rapid and large evolution of gas from a specimen in the early stages of burning on an enamel coat should have very little effect in forming blisters in the enamel.

87. It is only after the enamel coat has been fused over and completely covers the surface of the iron, that gas evolution will cause blisters. More probably, only the gas evolution which continues well toward the close of the firing period produces blisters which are not healed by the fused enamel.

88. In order to throw light on the relative rates of gas evolution (i.e., carbon oxidation) from irons at the various stages of the enamel firing period, another experiment was made. Enamel-sprayed strips of the most typical strongly blistering iron, 1-55, and of the three weakly blistering irons, 2-56, 4-55 and Southern 41, were cleaned by the usual sand-blast procedure, sprayed with the standard ground-coat enamel, dried and fired for varying periods of time up to a total of 20 minutes.

89. The evolved oxides of carbon were determined in the manner previously described. The results are given in Fig. 5.

90. From this figure it is evident that the amount of carbon oxidized and the rate of oxidation were nearly the same for all the weakly blistering irons and for the two runs with L_2, 1-55 (the strongly blistering iron), up to a firing time of about 8 to 10 minutes.

91. At the 8- to 10-minute firing period, however, the rate of carbon oxidation fell off very noticeably with all three* of

*A curve for Southern iron 41 has not been drawn in Fig. 5, since for that iron only one value for CO_2 evolution was obtained between the 4-minute and the 16-minute firing periods. The points for this iron are given in the figure and indicate that the curve would not differ greatly from those for the other weakly blistering irons.

the weakly blistering irons, and there was almost no evolution of gas (oxidized carbon) from these irons from 10 or 12 minutes to the 20-minute limit of the firing periods of this test. Gas evolution practically ceased over that portion of the enamel-firing period during which it would naturally be expected to cause blistering.

92. Of course, the whole cycle might be completed in a much shorter time in a furnace of greater heat capacity. Furthermore, it should be borne in mind that the first part of this period corresponds approximately to firing the ground coat, and the

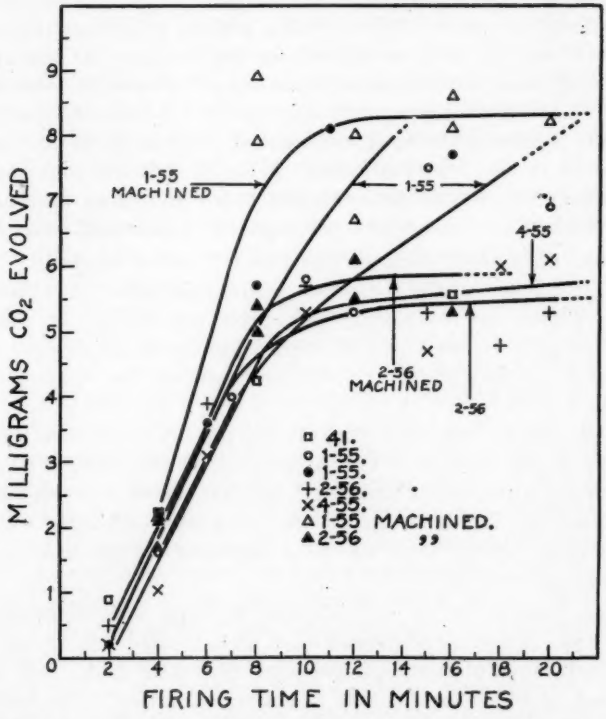

FIG. 5—WEIGHT OF EVOLVED CO PLUS CO_2 (CALCULATED TO CO_2), PLOTTED AGAINST FIRING PERIODS. ALL SPECIMENS COMPLETELY COATED WITH GROUND COAT AND FIRED AT 875 DEGS. CENT. (1605 DEGS. FAHR.) IN CO_2-FREE ATMOSPHERE. EACH POINT REPRESENTS ONE SPECIMEN AND CORRESPONDING ANALYTICAL DETERMINATION. L_2 (1-55) IS STRONGLY BLISTERING IRON; ALL OTHERS (INCLUDING L_2, 1-55, MACHINED) WEAKLY BLISTERING.

latter part to the additional heating that is necessary in firing the cover coat. It is during the latter part of this second period that it is important for gas evolution to be kept at a minimum.

93. The two curves for the duplicate runs with iron L_2, 1-55, the badly blistering iron, show no decrease in rate of carbon oxidation at the point where the curves for the weakly blistering irons flatten out; but they indicate a continuing evolution of oxidized carbon practically to the end of the firing-period used. Whether or not the curves flatten out here is not certain in the absence of additional points beyond the 20-minute firing period.

94. The question arose as to whether the curves, which flatten out at the 8-10-minute firing period, might begin to rise again if heating were continued—as, for instance, in the application of three or more coats of enamel. While these tests (Fig. 5) were not carried beyond 20 minutes in any case, the fact that blisters seldom occur on a re-enameled casting, which may have blistered in the first enameling, seems to indicate that such a secondary rise in the gas evolution curve, if it does take place, does not begin soon enough to give trouble in practical enameling.

95. The above data on the rate of carbon oxidation from the surface of enamel-coated cast-iron specimens all relate to iron cleaned by the normal sand-blast procedure. It will be recalled that machining a 0.003-in. layer from the surface of a strongly blistering iron strikingly reduced the tendency to blister.

96. If the cessation of oxidation of carbon relatively early in the firing period is the controlling characteristic of non-blistering irons, as is indicated by the curves for sand-blast-cleaned irons in Fig. 5, then a blistering iron—from the surface of which a 0.003-in. layer has been machined—might be expected to behave similarly.

97. Specimens of L_2, 1-55, and R_2, 2-56, were machined in this way, lightly sand-blasted and then treated exactly as the regularly sand-blasted specimens of the same irons had been treated, to determine the rate of carbon oxidation. The data on CO_2 evolution from the machined specimens are plotted in Fig. 5.

98. These curves show that machining off the surface of iron R_2, 2-56, had no influence on the rate of carbon oxidation from its surface, nor on the point at which oxidation of carbon ceases. Machining off the surface of L_2, 1-55, however, noticeably

increased the rate of carbon oxidation during the first 8 minutes of the firing period, but at the 8-10-minute point the evolution of oxidized carbon practically ceased.

Correlation of Gas Evolution Data with Previous Data

99. It was found possible to distinguish between strongly blistering and weakly blistering irons on the basis of the breadth of the range of firing periods within which enameling could be accomplished with relative freedom from blisters. The data obtained seemed to lead to several generalizations.

100. If an iron has a sufficiently strong blistering tendency, this range will be so narrow that it is virtually non-existent. An iron having a somewhat weaker blistering tendency gives much better results at 7½ minutes and even at 10 minutes of firing the ground coat than at the longer periods, while with the best iron R_2, 2-56, the range is so broad that the results are still relatively good at the 15-17½-minute periods.

101. In all cases, however, the average results at 3 minutes are unsatisfactory. The question arises as to just how these facts fit in with the foregoing data on gas evolution.

102. In the first place, it is obvious that the amount of blistering will be controlled by the rate of gas evolution during the part of the firing process in which the cover coat is able to entrap the evolved gas, i.e., after it has definitely begun to fuse. With this fact in mind, it can be seen readily that, when the firing period of the ground coat is very short, then (Fig. 5) blisters should be expected to appear on even the best irons studied, since the cover coat will be fired while gas is still being evolved just as rapidly as from a strongly blistering iron.

103. In the case of the specimens which are fired longer, there are three factors to take into consideration. One, of course, is the steepness of the gas-evolution curve during the critical period; another is the degree of permeability of the ground coat, which is increased as the ground-coat firing period increases, and third is the time-lag factor which influences the actual progress of the gas bubbles through the comparatively thick cover coat.

104. With any specific firing treatment, the number and character of blisters will depend upon the rate of gas evolution (i.e., steepness of the gas-evolution curve) during the critical part of the firing period. An iron in which this rate is *inter-*

mediate will give comparatively good results within a narrow range at the shorter firing periods.

105. This is because the comparative impermeability of the ground coat and the time necessary for the evolved gas to work its way through the cover coat, combine to delay the actual appearance of blisters at the surface of the specimen. If the ground coat is fired longer on an exactly similar specimen, it will not be impermeable enough to prevent the appearance of blisters during the firing of the cover coat.

106. An iron in which the gas evolution is sufficiently *copious* during the critical period will give numerous blisters even at the most favorable firing period, although the effect of the lower permeability of the ground coat at this period is appreciable.

107. If gas evolution has practically ceased before the cover coat is fired, the added permeability of the ground coat at the longer firing periods has but little effect, although its over-fired condition may be partially responsible for such blisters as do appear. Such an iron may be said to have a broad firing range.

Carbon in the Micro-Chilled Surface

108. All of these tests described above serve to indicate, if not to prove, that the blister-forming gas is not SO_2, hydrogen from the decomposition of steam, nor nitrogen from the decomposition of iron nitride. In all probability, it is CO_2 and CO.

109. There is good evidence that the reactivity of different varieties of carbon and graphite varies very greatly with the ratio of surface to volume of the particles, and with the mode of formation of the particles.

110. Moreover, the CO and CO_2 formed by the oxidation of any form of carbon will affect the rate of decomposition of cementite both by decarburization—which alters the amount of carbon and hence its distribution between the graphitic and combined forms—and, probably, also by a catalytic action.

111. It has been noted in commercial enameling that adhesion of enamel, for which a certain degree of oxidation of the surface of the iron is thought to be desirable, varies according to the size of the load with respect to the size of the furnace. This indicates that there may not always be enough oxygen available in the furnace atmosphere effectively to oxidize a large surface of graphite particles.

112. The weight of evidence strongly indicates that carbon in some one or more of the possible forms—ordinary graphite, submicroscopic graphite, temper carbon, or combined carbon (cementite)—plays a major role in the formation of blisters, and the problem appears to resolve itself into a study of carbon in the micro-chilled surface.

Ordinary Graphite

113. It seems unlikely that massive graphite is responsible for blistering. It is true that finely divided graphite smeared on the surface of the iron—as by writing on the iron with a pencil—gives blisters, and that carbonaceous mold facings are probably to be avoided, although very light applications have been successfully used.

114. One might assume that in severe sand blasting, which is known to minimize blistering, the graphite flakes may be dug out and removed and leave a practically graphite-free surface. Microscopic examination, however, shows that graphite flakes may extend to the very surface of the metal without causing blisters (see Fig. 6C).

115. On the other hand, graphite flakes may appear at the very surface, and the specimen blister. Such flakes may cause local poor adherence of the enamel, but poor adherence does not seem to be necessarily connected with blistering.

116. The machined surface of blistering iron L_2 does not blister, and it is very certain that machining does not drag out and remove all the graphite flakes. Massive graphite in itself cannot be considered as invariably producing blisters.

Submicroscopic Graphite

117. The assumption was made that, aside from the regular graphite particles visible under high and low magnification, there are particles beyond the resolution of the microscope. On account of their small size, these particles should be very active and should readily respond to the heat, i.e., they may agglomerate to somewhat larger groups, or may burn away, depending upon the temperatures used.

118. A certain confirmation of this idea is given in the following statement by Ropsy[4]:

"In fact, in the hardened part of a chilled casting (cooled,

[4] Ropsy, P., *Carbon in Cast Iron*, Foundry Trade Journal, 36, 1927, p. 199.

therefore, very rapidly and solidified almost without transformation) there remains up to 0.15 per cent of carbon in the form of graphite. To effect this determination with precision, at least 5 grams of metal must be dissolved, the determination of graphite being carried out on the residue. The microscope, even with the highest magnification, does not show this graphite, probably because it is disseminated throughout the mass in the form of particles which are too minute."

119. If these particles are, in fact, disseminated "throughout the mass," it is obvious that they could cause the evolution of gas even after the removal of the surface layer of a casting, and that they may be responsible for a large evolution of gas in the first period of firing.

120. In fact, it is believed probable that the comparatively rapid evolution of gas during the first 8-10 minutes of firing (Fig. 5) is in all cases caused by the oxidation of these submicroscopic particles of graphite, which are presumed to be present in approximately equal concentration (1) in the surface layer of the weakly blistering iron, (2) beneath the surface of the weakly blistering iron and (3) in the surface layer of the strongly blistering iron; but in greater concentration beneath the surface of the strongly blistering iron. In all cases the oxidation of this type of carbon is probably completed in the 8-10-minute period and is not responsible for any subsequent evolution of gas.

Combined and Temper Carbons

121. As pointed out in the introduction, chilled iron, with practically all of the carbon in the combined form, has been said by some to blister and by others not to blister. It was thought that the explanation of this difference of opinion might lie in the individual conditions surrounding each observation, which in some cases tend to promote and in others to retard graphitization.

122. These conditions are believed to include the degree of massiveness of the cementite formation, the presence or absence of elements which tend to stabilize cementite, superheating of the melt and other conditions. In order to throw some light on this question, several experiments were carried out.

123. Samples of a white iron (plow shares, donated by the Lynchburg Foundry Co., Lynchburg, Va.) were subjected to the standard enameling tests and were found to blister badly

over the whole range of firing temperatures. Specimens from which the surface had been deeply machined blistered as badly.

124. On annealing this white iron at 950 degs. Cent. (1740 degs. Fahr.) for five hours and cooling in the furnace, the tendency to blister was much reduced, the specimen tested at the shorter firing periods of the "range" method being practically perfect. The surface was decarburized by the long heating.

125. However, specimens from which the decarburized surface had been removed by machining—so that the enamel was applied on a surface that was not decarburized—were equally as good as those enameled on the decarburized surface. Such long annealing was not required, since heating to 900 degs. Cent. (1650 degs. Fahr.) for 45 minutes, followed by furnace cooling, was also effective in greatly diminishing blistering.

126. The annealing altered the structure decidedly by producing well-agglomerated "temper carbon," i.e., practically massive graphite. In the short heating of the enameling process there was evident decomposition of cementite, but very little agglomeration.

127. On the other hand, a specimen of malleable iron in which microscopic examination showed most of the temper carbon to be well agglomerated did not blister (rating 1) when the firing time of the ground coat was 7½ or 10 minutes, but blistered badly (rating 4 to 5) at 12½ and 15 minutes. Well-agglomerated temper carbon thus appears nearly as non-reactive as massive graphite.

128. The great activity of colloidally dispersed temper carbon, just as it forms and before it agglomerates, is in sharp distinction to the lower reactivity of the agglomerated material.

129. In order to study a mild chilling effect on the weakly blistering castings, the iron R_2 was cast in the usual $\frac{3}{16}$-in.-thick plates in a variety of sand molds—(a) skin dried; (b) moisture content, 6 to 7 per cent; (c) moisture content, 10 per cent.

130. The specimens were enameled in the regular way, save that the time of firing of the ground coat was 12½ minutes instead of 8 minutes as heretofore, since the longer time of firing seemed to accentuate the tendency to blister. All specimens were graded No. 2 with respect to blistering. These results indicated that variations in moisture content of molding sand could not be held wholly responsible for variations in chill that would cause blistering.

131. The decomposition of cementite from combined carbon to temper carbon or graphite, which occurs in a chilled or microchilled layer during enameling, will doubtless depend on (a) the original content of combined carbon, (b) the composition of the iron as to elements that promote or hinder graphitization, and (c) the time and temperature of enameling.

132. If all these conditions are such that there is no breakdown of combined carbon during enameling, it may be assumed that the iron does not blister, provided that the free carbon present is in such a state that it cannot cause any trouble.

133. Under this assumption, either stable white iron or stable gray iron would be "non-blistering." But, if the chilled layer contains combined carbon that does break down to colloidally dispersed temper carbon during a certain period of the enameling process, it will blister.

134. If the enameling process is carried out at a high temperature and for a long time (e.g., 15- and 17½-minute firing periods) the blistering tendency will be accentuated either because the combined carbon, although stabilized, may begin to break down under this treatment, or because the graphite may begin to oxidize under such conditions. If the same iron is enameled at a short firing period, or at a lower temperature, or by using more fusible enamels, the iron may not blister.

135. Thus, the blistering for which combined carbon is responsible may be traced to the breakdown of combined carbon to temper carbon at a stage during enameling at which oxidation can occur and at which the enamel is in such physical condition as to retain the CO and CO_2 formed. If the breakdown at this stage is prevented, there will be no "nascent" carbon to cause blisters.

136. It may be prevented by the nature of the chilled layer itself, or by removing the offending surface layer or avoiding conditions that will produce this layer, or by decarburizing the surface, or by accomplishing the breakdown before the enameling operation.

Recapitulation

137. To recapitulate, stable cementite is not necessarily readily oxidized to give the CO_2 or CO gases that appear to be responsible for blistering. Neither does massive graphite—

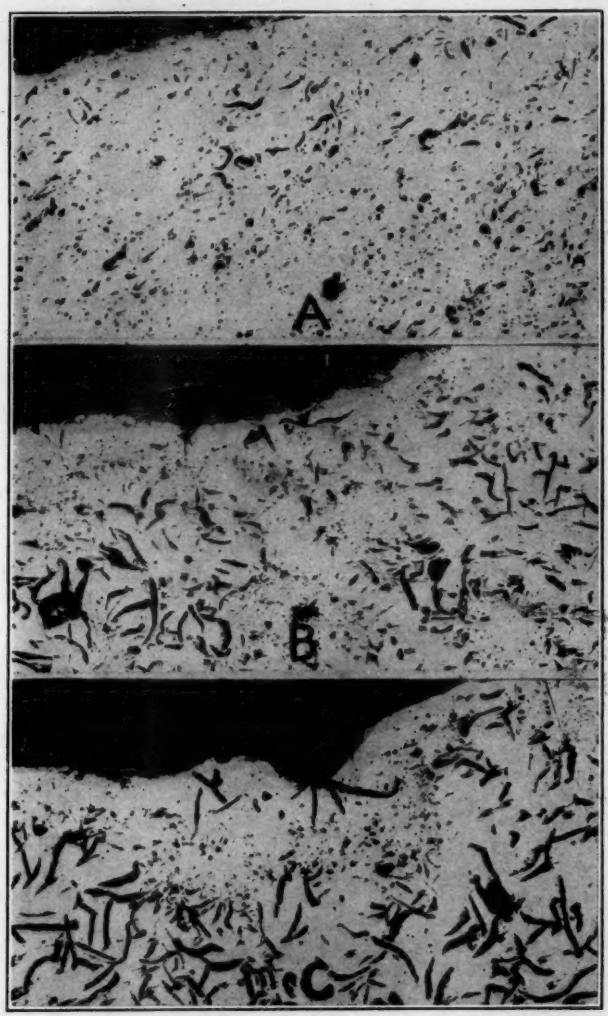

FIG. 6—ILLUSTRATED AGGLOMERATION OF GRAPHITE PARTICLES UPON ENAMELING. IRON R_2, HEAT 48. POLISHED 100X.

A—DRAG SIDE EDGE OF CROSS-SECTION BEFORE ENAMELING.

B—SPECIMEN ENAMELED: GROUND COAT FIRED 3 MINUTES AT 875 DEGS. CENT. (1605 DEGS. FAHR.); COVER COAT, 8 MINUTES AT 800 DEGS. CENT. (1470 DEGS. FAHR.). NO BLISTERS OBSERVED.

C—SPECIMEN ENAMELED: GROUND COAT FIRED 10 MINUTES AT 875 DEGS. CENT. (1605 DEGS. FAHR.); COVER COAT, 8 MINUTES AT 800 DEGS. CENT. (1470 DEGS. FAHR.). NO BLISTERS OBSERVED.

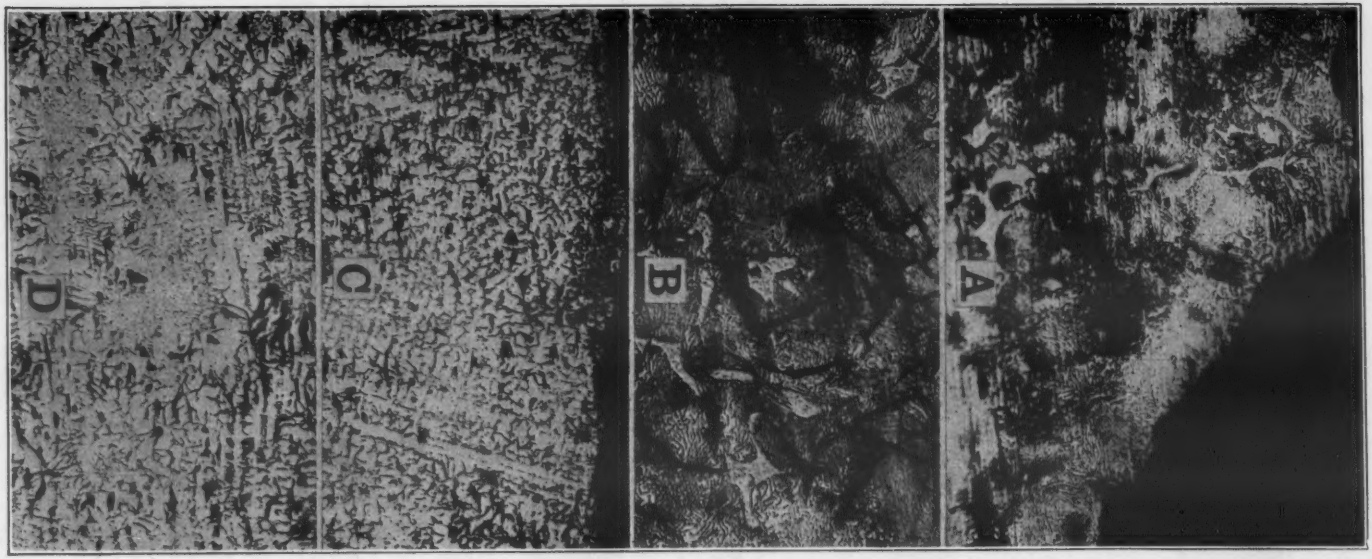

FIG. 7—CROSS-SECTIONS AT SURFACE AND INTERIOR OF BLISTERING IRON BEFORE AND AFTER ENAMELING. IRON L_1, HEAT 16. ETCHED IN 5 PER CENT PICRIC ACID. A AND B SPECIMEN BEFORE ENAMELING. 500X.

A—CROSS-SECTION AT DRAG SIDE. B—CROSS-SECTION NEAR CENTER OF CASTING.

C AND D—AFTER ENAMELING, 100X. C—PART OF CROSS-SECTION ADJACENT TO ENAMEL. D—CENTRAL PART OF CROSS-SECTION. A NUMBER OF BLISTERS OBSERVED ON THIS SPECIMEN. GROUND COAT FIRED 8 MINUTES AT 870 DEGS. CENT. (1600 DEGS. FAHR.); COVER COAT, 7 MINUTES AT 840 DEGS. CENT. (1545 DEGS. FAHR.).

Table 6

CHANGE IN HARDNESS OF BADLY BLISTERING IRON (L_1, L_2) AND WEAKLY BLISTERING IRON (R_1)

Iron	Melts	Heat No.	Carbon Total	Carbon Graph.	Carbon Comb.	Mn	P	S	Si	Hardness before enameling: Shore scleroscope	Hardness before enameling: Rockwell B scale	Hardness after enameling: Shore scleroscope	Hardness after enameling: Rockwell B scale	Decrease in hardness, per cent: Shore scleroscope	Decrease in hardness, per cent: Rockwell B scale
			Per Cent												
L_1	Cupola	6	3.65	2.97	0.68	0.56	0.46	0.05	2.16	47.4	96.2	33.9	79.8	28.5	17.0
L_1	Cupola	14	3.47	3.07	0.40	0.57	0.46	0.076	2.24	48.4	93.2	35.7	76.8	26.2	17.6
L_1	Cupola (melted 3 times)	16	3.47	2.95	0.52	0.33	0.47	0.095	1.92	50.4	96.8	35.1	81.3	30.4	16.0
L_1	Cupola (0.1% S in ladle)	22	3.59	2.99	0.60	0.56	0.45	0.121	2.22	47.3	95.6	36.4	81.1	23.0	15.1
L_1	Electric furnace	17	3.76	3.10	0.66	0.63	0.47	0.038	2.19	43.4	89.4	33.0	81.3	24.0	9.1
L_1	Electric (0.1% S in ladle)	20	3.81	3.09	0.72	0.65	0.45	0.10	2.13	46.8	93.8	32.9	80.5	29.7	14.1
L_1	Electric (0.13% S charged with iron)	28	3.67	3.09	0.58	0.61	0.43	0.092	2.21	46	94.6	33.1	82.5	28.0	11.1
R_1	Cupola	7	3.40	3.18	0.22	0.69	0.81	0.048	2.82	46	94.6	40.9	89.7	11.1	5.2
R_1	Electric (0.16% S added to molten iron in furnace)	26	3.58	3.09	0.49	0.77	0.79	0.09	2.93	42.6	92.2	35.8	77.3	15.9	16.2
L_2	Electric	44	3.60	3.15	0.45	0.71	0.49	0.043	2.44	46.5	93.3	38.5	75.7	17.2	19.0

whether formed as such during solidification and cooling of gray iron, or as a product of decomposition of cementite on annealing—appear responsible for blistering. It does appear, however, that an intermediate structure, resulting from the partial breakdown of cementite on annealing and partial agglomeration to graphite, is the most active in producing blisters.

138. The enameling process itself is a short anneal. The decomposition of cementite will be accelerated by the presence of graphite in the original casting. Agglomeration of small, widely distributed particles of primary graphite into large flakes is clearly shown by Figs. 6A, 6B and 6C, in which the progressively increased agglomeration of graphite particles with increased firing periods is very plain. Even the body of a gray-iron casting is changed in structure and hardness by the heat treatment incidental to enameling.

Change of Hardness and Structure on Enameling

139. Table 6 shows the decrease in hardness that takes place on enameling. Metallographic examination of a number of specimens showed that a considerable change in the structure of the iron occurred during the enameling process, and this change often was not confined to the surface layer but took place throughout the section of the specimens.

140. A specimen which, before enameling, contained a lamellar pearlite matrix throughout its section (Figs. 7A, 7B) after enameling showed the large ferritic areas and dendritic structure similar to those represented in Figs. 7C and 7D. The remainder of the pearlite was usually spheroidized or is changed to sorbite.

141. It was noted that some specimens of weakly blistering iron appeared to undergo no change detectable under the microscope during enameling. Fig. 8B, at 100 diameters, shows a weakly blistering specimen the surface of which, when examined at 500 diameters after enameling, appeared to be unchanged from the pearlitic structure of the un-enameled specimen shown in Fig. 8A.

142. It was thought for a time that a lower blistering tendency might be associated with a smaller change in structure, but it was found later that this was not always true, and that a marked change in structure often occurred in weakly blistering as well as in strongly blistering specimens.

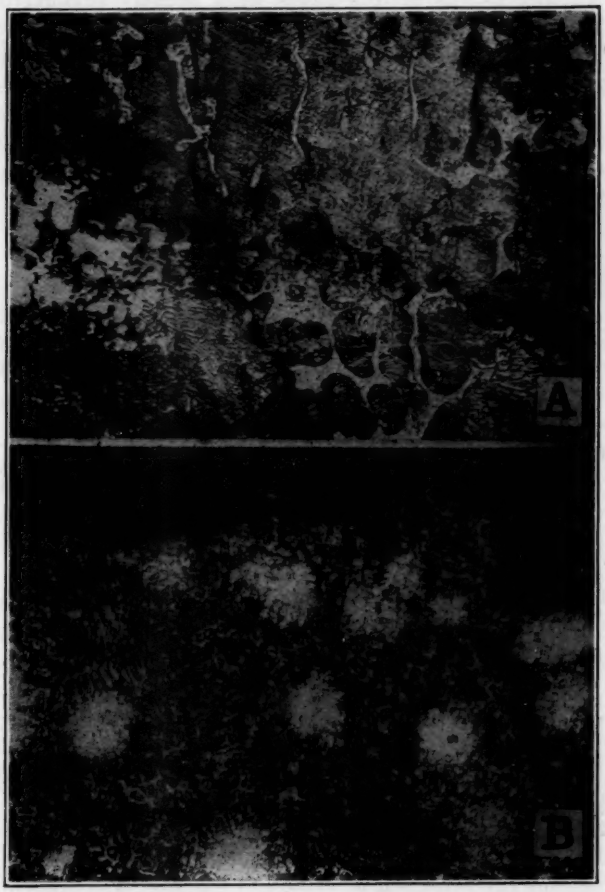

FIG. 8—CROSS-SECTIONS OF SURFACE LAYER OF NON-BLISTERING IRON BEFORE AND AFTER ENAMELING. ANALYSIS: C, 3.46 PER CENT; GRAPHITIC C, 2.85; COMBINED C, 0.61; MN, 0.52; P, 0.510; S, 0.101; SI, 2.22. ETCHED IN 5 PER CENT PICRIC ACID.

A—SPECIMEN BEFORE ENAMELING, 500X.

B—SPECIMEN ENAMELED, 100X. NO BLISTERS OBSERVED. GROUND COAT FIRED 5½ MINUTES AT 900 DEG. CENT. (1650 DEGS. FAHR.); COVER COAT, 6 MINUTES AT 840 DEGS. CENT. (1545 DEGS. FAHR.).

143. Much attention was paid to the habit of the graphite, i. e., whether it was in fine flakes, only slightly agglomerated, or almost entirely agglomerated in the "whirl" form; but the observations seemed to justify the conclusion that the habit of the graphite is not definitely associated with blistering tendency. This remark, however, cannot be applied to the superheated or graphite eutectic structures, where graphite is present in a very finely dispersed form, which probably would be in favor of blistering.

Burning Out

144. The familiar "burning out" or normalizing in air (so often resorted to by the enameler) to prevent blistering, may be considered as accomplishing various things. (1) It removes some of the surface layer of metal by oxidation. (2) It tends to decarburize and hence soften the layer of metal immediately beneath the oxide coat. (3) It softens the metal as a whole.

145. Hence, when a burned-out casting is sand blasted, the loose oxide comes off readily and the surface, now softer than before annealing, is more readily removed by sand blasting.

Effect of Elements in Cast Iron on Chilling Tendency

146. The formation of the micro chill appears to be a matter of delicate balance, as is evidenced by the fact that some heats of the strongly blistering Northern iron are shown to be better than some heats of the weakly blistering iron.

147. The question then arises, can the composition of the blistering irons be so adjusted that the micro chill will not form or will not be too deep and too hard for complete removal by ordinary sand blasting?

148. In order to bring this about, it would be quite natural to add some element that would tend to foster graphitization and prevent the retention of combined carbon. The addition of silicon, aluminum or nickel—well-known graphitizing agents—as previously discussed, indicated that some improvement may be accomplished by such means, particularly in the case of silicon, if added in the proper manner and proportion.

149. The "micro chill" appears to be more difficult to prevent than the ordinary chill, which can be readily controlled by properly adjusting the composition and the rate of cooling. However, it seems reasonable that changes that tend to prevent

the formation of the ordinary chill would also be steps in the right direction in the prevention of the micro chill.

SUMMARY

150. The data obtained in this investigation appear to support the explanation of blistering which is summarized in the following paragraphs, and which is the only one known to the authors that fits the facts observed thus far.

First.

151. There is ample evidence that physical defects, especially "sponginess," will give rise to blisters. Moreover, an enamel may be composed, prepared or applied in such a manner as to cause blisters, irrespective of the character of iron used.

152. There are, however, differences in the tendencies of sound castings, made from different lots of iron, or made from the same iron under different conditions, to give blisters when enameled under identical conditions. The gases forming the blisters are CO and CO_2.

Second.

153. A gray iron casting of the composition normally used for enameling acquires, in freezing and cooling in the mold, a very thin surface skin which may be considered as a "micro chill." This extends only a few thousandths of an inch below the surface and varies in thickness, hardness and resistance to abrasion by the sand blast, according to composition and conditions. Removal of this surface layer eliminates blistering, except such as is caused by sponginess or other physical defects which extend more deeply into the interior.

154. The analyses of the surface layers indicate that the hardness and resistance to abrasion may be due either to the higher combined carbon or to some other hard component.

Third.

155. The cementite (combined carbon) of this skin tends to break down, during the enameling process, to very finely divided "temper carbon." This form of finely divided carbon is more readily oxidized, as would be expected from its fineness, than massive graphite or combined carbon.

Fourth.

156. This breakdown to a nascent, readily oxidizable form of carbon, analogous to the early stages of the malleableizing of white iron, leads to the formation and evolution of CO and CO_2 upon heating, which causes greater or less damage, according to the stage of the enameling process at which it occurs. If the enamel coat is sufficiently fused to form the gas into bubbles, but not fluid enough to heal after any bubbles of gas have escaped, blisters will occur. If the craters partially heal, there will be dimples.

157. If the enamel is a low melting one, applied at a low temperature, the annealing action coincident with enameling may not be sufficient to produce a breakdown of the cementite, accompanied by the formation of the finely dispersed temper carbon; or, if it is produced and CO and CO_2 are formed, the enamel may be fluid enough to allow the gas to escape without damage.

Fifth.

158. There are probably two kinds of non-blistering iron—one in which a small amount of combined carbon is present in the surface layer; the other in which cementite is so stable that it takes a relatively long time to break down into ferrite and temper carbon.

Sixth.

159. Decarburization of the skin, as well as its removal by mechanical or chemical means, will eliminate the source of temper carbon. Hence, blister-free ware can be obtained with a sound casting if the enameling process itself is properly carried out, unless the whole casting is of such a nature that the body as well as the skin will give temper carbon on enameling.

160. Some irons have a greater tendency to give the microchilled layer than others. The gas evolution which apparently takes place during the first part of the firing treatment, even from those specimens having the least blistering tendency of any studied, has been assumed to be due mainly to submicroscopic graphite, which burns out too quickly to cause blisters.

Seventh.

161. Aside from such variations as may be attributed to

differences in enameling procedure at the different plants, the presence of a hard surface layer or micro chill probably accounts for most of the inconsistencies observed in the investigation, as well as those between the results of various laboratories. Unless sand blasting is uniformly controlled and the surface layer uniformly attacked, it is obvious that erratic results will be obtained on enameling.

Eighth.

162. Attempts to nullify the hardening effect of sulphur by addition of manganese do not appear to offer much hope, since excess manganese in itself is harmful. Addition of some softening agents such as silicon, or any precaution in casting that will tend to minimize the tendency to chill, may be beneficial; but it is much more difficult to prevent the formation of the micro chill than the formation of the well-understood ordinary or macro chill.

Ninth.

163. In cases when an occasional heat or lot of sound castings shows a tendency to blister, burning-out or deep sand blasting appears to be the most practical remedy.

ACKNOWLEDGMENTS

164. The work reported above by no means represents the efforts of any one person. It would have been impossible for the investigation to be carried out without the cooperation of various individuals whose contributions were of great importance. Suitable acknowledgment is given in the full report of the investigation. Especial and grateful acknowledgment is made here to H. W. Gillett, C. M. Saeger, Jr., and L. Jordan.

APPENDIX

Enameling Test "Range" Method

165. The basis of the test was that each iron should be enameled under a variety of firing treatments instead of a single one, and that irons should be distinguished from each other according to the breadth of the range of treatments within which blister-free ware was produced. Seven pecimens were required to make a test and, for the particular enamels which had been supplied the Bureau, the following schedule was used.

166. The ground coat was fired at 875°C. (about 1,605°F.) for varying lengths of time on different specimens. The first specimen was fired

Table 7

STANDARD GROUND COAT AND COVER COAT ENAMELS

Batch Weights			Melted Weights		
Raw material	Ground coat	Cover coat	Ingredient	Ground coat	Cover coat
Feldspar		34.70	SiO_2	67.40	14.30
Quartz	67.40	14.30	B_2O_3	17.04	8.91
Borax	37.10	24.30	Na_2O	8.35	7.13
Red lead	7.35	16.05	PbO	7.16	15.70
Boric acid	6.07		Feldspar		34.70
Soda niter	6.39		K_2O		1.27
Potash niter		2.73	Cryolite		4.28
Soda ash		5.47	ZnO		7.02
Fluorspar		5.47	CaO		1.23
Cryolite		4.28	CaF_2		5.47
Zinc oxide		7.02			
Whiting		2.22			
Total	124.31	116.54	Total	99.95	100.01

for three minutes, the second five minutes, the third 7½ minutes, and so on by 2½-minute increments until the seventh specimen was fired 17½ minutes. Then the cover coat was applied to all under uniform conditions, being fired for eight minutes at 800°C. (about 1,470°F.).

167. The enamels shown in Table 7 were used. To each 3 × 6-in. casting, the ground coat (spec. grav. 1.53) was applied in a wet weight of 3.0 to 3.6 grams and the cover coat (spec. grav. 1.91) in a wet weight of 23 ± 1 grams.

Table 8

SUPPLEMENTARY LIST OF IRON COMPOSITIONS

Designation of irons	Character	Composition, per cent						
		Tot. C	Graph. C	Comb. C	Mn	P	S	Si
Pig iron, Southern	Weakly blistering	3.55	3.15	0.40	0.24	0.82	0.021	2.73
Pig iron, R_1	Weakly blistering	3.62	3.06	0.56	0.78	0.83	0.029	2.99
Pig iron, R_2	Weakly blistering	3.61	2.96	0.65	0.68	0.78	0.045	2.66
Pig iron, L_1	Strongly blistering	3.81	3.15	0.66	0.67	0.46	0.045	2.31
Pig iron, L_2	Strongly blistering	3.73	3.14	0.59	0.78	0.50	0.090	2.55
Heat 16, L_1	Strongly blistering	3.47	2.95	0.52	0.33	0.47	0.095	1.92
Heat 41, Southern	Weakly blistering	3.46	3.14	0.32	0.24	0.83	0.020	2.80
Heat 43, R_1	Weakly blistering	3.40	2.88	0.52	0.60	0.77	0.021	2.55

168. Different lots of castings reacted to this test in various ways. One lot might give the best results when the ground coat had been fired for five minutes, and another when it was fired for seven and one-half, while a third would be almost free from blisters throughout the range of treatments.

DISCUSSION

ORAL DISCUSSION

MEMBER: What pressure of sandblast is used in America for enameling work on cast iron? In England we use 80 lbs. pressure.

A. I. KRYNITSKY: We used 60 lbs. pressure in the work described.

MEMBER: Mr. Krynitsky, after this normalizing or preliminary heating up measure which you advise, are the castings left in a good enough condition for enameling, or do they need to be cleaned afterward? After you have had them in the muffle for the period you advise to clean the surface, or to burn the carbon from the surface before you enamel, is the surface good enough to take the enamel without being sandblasted to remove any scale?

A. I. KRYNITSKY: The usual method is to sandblast again after the heat treatment. On this matter of sandblasting, I said that we use 60 lbs. pressure, but I did not quite finish my statement. We have a certain standard for sandblasting, which is to keep the specimen four inches from the nozzle, at right angles to the direction of blast. The time is 45 seconds for a 3 x 6 inch specimen.

MEMBER: In this country, is it the general practice to use any special mixture of sand, especially with regard to the proportion of coal dust, as we call it—or sea coal—so as to avoid getting a carbonaceous surface? We all know that if we use a very large proportion of sea coal, we get castings that strip very readily and look very nice and smooth. However, it does not necessarily follow that if we use a large proportion of coal dust, we get castings that are satisfactory for enameling work.

A. I. KRYNITSKY: Our molding sand in all these experiments has been 00 Albany sand, and no graphite mixtures were allowed. However, we made a few experiments with graphite facings, with very poor results. When we attempted to use sea coal or special graphite compounds, severe blistering resulted.

MEMBER: Do the people who perform this work for enameling in this country use sand with sea coal? We use sea coal in England with our sand for enameling work, but it has its disadvantages.

A. I. KRYNITSKY: I cannot answer that question. One company here, to my knowledge, obtained satisfactory results with very light plumbago facings.

MEMBER: With regard to the two irons you suggest, Mr. Krynitsky —one that gives a fairly pearlitic structure—presuming that the surfaces

are equally clean, do you think that an iron with a pearlitic structure, a hard iron, enamels as well as a soft iron?

A. I. KRYNITSKY: A pearlitic structure, or rather, a hard iron, does not enamel as well as a soft iron. As a rule, that is the case, but there are many exceptions. In general, a soft ferrite matrix in the surface layer gives better results.

MEMBER: That seemed to me to be the case, because in much of the products that we make in England for enameling—the tops, for instance, of electric cookers, which afterward are somewhat subjected to local heat—it seems to me that an iron high in pearlite would be much more likely to crack after prolonged heating at comparatively low temperatures.

MEMBER: In connection with sandblasting, did I understand correctly that a sample was taken—one-half of which was sandblasted and the other half of which was not sandblasted—for test purposes, and that the part sandblasted properly had less blisters than the other part?

A. I. KRYNITSKY: The strip which was completely shielded from the blast was free from blisters. The enamel was not adhering, but it did not blister. In other words, the blistering was not caused by burnt-in sand.

H. KOHNLE:* When you speak of enameling, do you mean porcelain enameling, Mr. Krynitsky?

A. I. KRYNITSKY: Yes, vitreous enameling.

H. KOHNLE: Considering the scale-manufacturing business, for instance, our common custom scales are all enameled—porcelain enameled. We have a great deal of trouble with the porcelain on account of blisters on the cast iron.

The customers blamed us for our low phosphorus. The job formerly was handled by a production foundry in Chicago—with very good success, it was claimed. However, their irons all carried phosphorus at 0.70 or over, and our iron was at 0.20 phosphorus and under.

We had some trouble with our irons and all our trouble was blamed on the low phosphorus. Have you had any experience along that line?

A. I. KRYNITSKY: If you will examine the composition of our irons, you will see that it so happened that the non-blistering iron contained about 0.8 per cent phosphorus, whereas the blistering iron contained about 0.5 per cent phosphorus.

In one case we took a blistering iron and added phosphorus and other elements to bring the composition of the "L" type to the "R" type. The "L" type is the blistering, while the "R" type is non-blistering. We obtained almost the same composition in the "L" type, but it blistered just like the others.

Thus, the artificial composition did not help at all. It so happens, however, that the "R" irons—Southern irons—which are recognized as non-blistering irons, have about 0.8 per cent phosphorus. Of course, phosphorus gives more fluidity and it is easier to produce castings.

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*Superior Casting Co., Dayton, Ohio.

However, I do not know whether one can definitely tie up the phosphorus content with the question of blistering and non-blistering.

MEMBER: The bulk of our stove-grade iron in England runs about 1.5 to 1.8 per cent phosphorus. We run up to 1.7 phosphorus with much of our stove-grade work, and I have never heard of any trouble through high-phosphorus iron.

A. I. KRYNITSKY: Some time ago a man from England was over here and, naturally, we were very anxious to know how this problem was solved in England. He said that it was solved in a very simple manner. He said they know that certain blast furnaces over there produce irons that do not blister, so they buy their cast iron from them.

H. KOHNLE: While we had trouble with some particular parts of the scale from blistering with those low-phosphorus irons, we had 60 per cent of the scale parts that didn't blister at all—they enameled fine. All the blistering happened to be in a certain design of casting. Still, our customers claimed it was the low phosphorus that was doing the damage and causing all the trouble.

J. L. HOLMQUIST:* With regard to the amount of surface reaction which we get from the casting, we have found experimentally that the thickness of the casting is a very important factor. A casting which is 1/16 or 3/32 inch thick blisters much less after normal sandblasting than a casting ¼ or ⅜ inch thick.

With regard to Mr. Kohnle's experience with certain parts of his castings blistering more than others, does he remember whether or not that blistering was excessive on the heavier parts of the casting?

H. KOHNLE: I cannot answer that positively. The casting with which we had the most trouble was generally very uniform in thickness all over—I should say about ⅛ inch thick, or perhaps a little more. Of course, naturally there would be strains and other circumstances that would cause sections to be a little heavier.

J. L. HOLMQUIST: I understood, Mr. Krynitsky, that your thinner castings did not blister nearly so much as the thicker castings.

A. I. KRYNITSKY: I would say that in the thinner sections there is probably more stable combined carbon, because of the chilling effect. Such stable combined carbon may tend to diminish blistering.

J. L. HOLMQUIST: We find, in general, that anything which accelerates the rate of solidification seems to diminish the amount of surface reaction obtained. Whether it is by pouring at lower temperatures or using a mold with higher heat conductivity, or whatever it is, the thickness of the casting does seem to have a considerable effect.

A. I. KRYNITSKY: Some claim that the white iron does not blister, and I believe that in some cases this is correct.

J. L. HOLMQUIST: We have cast plates in cast-iron molds which had a chill 1/32 to 1/16 inch thick of white iron that did not blister—in fact, it enameled almost as well as a machined surface.

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*Standard Sanitary Mfg. Co., Pittsburgh.

A. I. KRYNITSKY: Probably the conditions were such that the combined carbon did not break down in that instance. With unstable conditions, blistering can be expected. If it is stable, there is less likely to be blistering.

B. T. HAIN:* Has there been any experimentation to determine whether or not the surfaces blister more when made in the cope or in the drag of a mold?

A. I. KRYNITSKY: As a matter of fact, we always intended to enamel the drag side; however, sometimes we have enameled the cope side by accident. We did not find much difference.

B. T. HAIN: Were any experiments ever made as to the addition of any steel in shot form to the ladles to shorten or set the iron more quickly, and if so, was any difference found in the enameling process?

A. I. KRYNITSKY: We did not carry out those experiments, but recently we obtained cast iron which could not be enameled at all, except within a very narrow range of enameling conditions. Grinding, machining off the surface layer and annealing did not help at all.

We examined it under the microscope and analyzed it, and it looks to me—so far as we have been able to tell from a brief examination—that this iron is of the eutectic type, perhaps the superheated type. Then we found that this iron was produced in the electric furnace, and with the addition of a good percentage of steel scrap.

We did not make such experiments as you mention, Mr. Hain, but it may be a good suggestion for someone to experiment with the superheated iron, or graphite eutectic-type iron. That iron is very good from the mechanical standpoint, but probably not so good for enameling purposes, because the graphite is present in a very fine dispersion.

B. T. HAIN: I do not know just what the addition of steel shot does to separate the carbon, but we have been experimenting some with irons that are regularly used with the dry process of enameling. We find that trying to put wet-process enamel on those irons works very badly, resulting in an excessively blistering surface.

However, in the making of an iron and casting those same castings, the addition of some metal punchings in the ladle has materially affected the job that we do. It makes a very much better job than trying to put the wet-process enamel on that kind of iron. The material added was a straight carbon steel.

MEMBER: On the question of eliminating blisters, at times we find a small amount of blistering along the rim of certain castings. I have always felt that this was due to the fact that the sandblasters neglected to sandblast the casting properly. We have found—if we would pick out a similar casting from the same lot of work going through, take it back to the sandblast and have special supervision on it—that it would go through without any blisters.

Also, in experimenting a bit in our slush coat with the adding of quartz in the base coat, I have found that blistering has been reduced considerably.

*American Radiator Co., Buffalo.

Status of Foundry Sand Control as Seen by the Sand Producer

By W. Worley Kerlin,* Conneaut, Ohio

Abstract

The three most important physical properties of a sand are venting factor, strength and temper. To keep these in proper proportions for molding and casting, tests of the heap sand are necessary. These properties, which make for stability in heap sand, are dependent to a large extent upon the qualities of new molding sand. A sand producer, therefore, must have information as to the chemical analysis, colloidal bond and screen analysis of his deposits. The methods available to the producer who seeks to control his shipments are outlined.

1. The object of routine sand testing of sand heaps is to express in precise terms the three physical properties that are the most important in the sand structure of a mold. This is the final stage in a program of sand control, which begins with the more fundamental work of finding the proper ingredients for making up the heap.

2. The properties most desired in a mold are (1) proper vent, (2) strength and (3) temper. The methods which measure these in terms of permeability, strength and moisture content have been described in other papers[1] and are well understood.

3. It is the purpose of this paper to tell something of the relationship between the properties of new sand and of its effect on the heap, and to indicate how far heap sand can be controlled by proper regulation of the raw materials entering the heap.

Heap Sand Control Important

4. Since the prepared heap is nearest in point of processing to the most crucial point in the manufacture of a casting—

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[1] Standard and Tentatively Adopted Methods of Testing and Grading Foundry Sands, American Foundrymen's Association, July, 1928.

namely, the molding and pouring operations—the regular testing of the heaps aids in their final conditioning. These tests must be made rapidly in order to detect any irregularity before the mold is poured.

5. From his knowledge of properties of raw materials, the sand tester knows about what to expect from his heaps at this stage. By the regular addition of a given sand he knows what permeability to expect.

6. This permeability is seldom that of the raw sand, but the ratio between the new and the used condition is fairly definite. Certain sands may increase the strength and firmness of the mold without raising bond content or without decreasing permeability.

7. This faculty abides in the grain structure of the sand. It is this property which brings out the full effect of surface tension on strength when the sand is tempered in this instance. This is just one example of how the structure of molding sand may affect the final properties of the heap.

LABORATORY CHECK OF RAW MATERIALS

Important Properties

8. The properties which make for stability in sand heaps are found in the nature of the new molding sand used. Grading and chemical analysis will describe these properties most accurately. It is in these primary laboratory tests that the explanation for most of the properties of strength and permeability lies.

9. The tests involved here include:

1—Chemical analysis.
2—Colloidal bond.
3—Screen analysis.

10. A fourth property is grain shape, which can only be described in such general terms as "rounded," "angular" and "sub-angular."

Chemical Analysis

11. Chemical analysis is most useful when molding sand is considered as a mechanical mixture of sand grains and bond. These two constituents should be separated before actual chemical analysis is begun.

12. Two definite chemical compounds can then serve as

guides to the properties of the sand. One compound is pure silica—this is the ideal which the grain residue will approach as its heat resistance increases. The other compound is pure kaolin, which has the following composition:

	Per Cent
Silica (SiO_2)	46
Alumina (Al_2O_3)	39
Combined water (H_2O)	15

13. Kaolin is the main constituent of the colloidal bond in a molding sand. The different proportions in which these three compounds occur in the clay matter indicate the heat resistance and the efficiency of the bond. Burning-out in a molding sand involves the destruction of this compound through dehydration. Dehydration begins at 300 degs. Fahr. and proceeds in varying stages of completeness up to 1200 degs. Fahr.

Dehydration Test

14. Since these temperatures are much lower than the fusion temperature of either clay or silica, it suggests a test which is liable to contain more information about the heat resistance of a molding sand than would the actual fusion temperature of the whole sand.

15. Presence of impurities affects the heat resistance of sand. Lime lowers the fusion point of the grain or bond. Iron oxide has an effect similar to that of lime.

16. The presence of this impurity is not altogether bad, as Brown and DeWitt[2] have shown in their study of the effect of a film of hydrated iron oxide on sand grains in natural molding sand. They have shown by strength tests that this film increases the efficiency of bond.

Bond or Strength

17. The second property in which the producer is interested is bond. As the standard method for determining bond (recommended by the A. F. A. Committee on Molding Sand Research) becomes more widely used, it becomes easier to compare sands from various sources of supply with one another.

18. The old volume test is useful in comparing the bond content of sand with similar grain distribution, but this method fails as a means of comparison in most other cases. The percentage shown in a volume test is influenced by the extent to

[2] TRANSACTIONS, A. F. A., vol. 36 (1928), p. 247.

which the grain residue will pack when vibrated, as well as by the amount of colloidal bond in the sand.

19. The most direct effect of bond is on the strength of the sand. Amount of bond also has a direct bearing on the tempering range of the sand—the higher the bond content, the more moisture will be required to bring out the full effect of this bond.

How Producers Can Help

20. The producer can be of service to the foundryman by supplying sand with constant bond content and of uniform grain distribution. Then, every time the sand is tempered up to a certain "feel" of wetness to the hand, a check of moisture content will show it to be within specified limits. This is especially important on continuous units where sand is tempered on belts by a man who regulates the water additions by the "feel" of the tempered sand.

21. When the grain structure and bond content of sand are held constant from day to day, this operator can regulate his tempering most accurately. However, this can only be done by regular additions of a new sand of uniform properties.

22. Because of the time required to wash out the bond, it is not always convenient for the laboratory to check bond content as a regular procedure. Moreover, percentage of bond does not tell the whole story, since the base grain distribution has just as important an effect on the tempering range.

23. This difficulty is best overcome by specifying a sand with a maximum permeability which comes within a certain moisture range. This moisture range will not be the same as the desired moisture content of the heaps, but it will bear a definite relationship to it. A little investigation along these lines will provide a rapid method of checking every carload of sand purchased as to its combined properties of bond content and grain distribution.

Screen Analysis

24. Final step in the examination of a molding sand is the screen analysis of the grain residue after the bond has been washed out. This is a subject for basic sand research in the foundry, but it may be mentioned here as a means of getting the fineness number.[3]

[3] TRANSACTIONS, A. F. A., vol. 36 (1928), p. 707.

25. The results from this screen analysis may be plotted cumulatively on the Tyler standard screen scale shown in Fig. 1. The screens for this analysis are chosen from those recommended by the Committee on Grading of the A. F. A. Committee on Molding Sand Research, with mesh areas decreasing in the ratio of 2 to 1 for each successive screen. This gives a curve which is

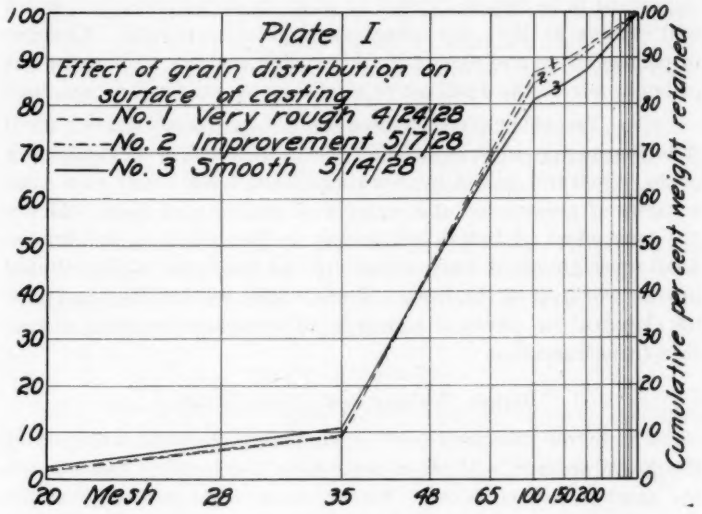

FIG. 1.—CUMULATIVE DIRECT DIAGRAM OF SCREEN ANALYSIS ON SAMPLES OF HEAP SANDS FOR BOILER SECTIONS, TAKEN ON TYLER STANDARD SCREEN SCALE, AT SCREEN SCALE RATIO 1.414. ANALYSIS SHOWS FOLLOWING DATA:

	Sample No. 1		Sample No. 2		Sample No. 3	
Mesh Size	Per cent.	Per cent cumulative weights.	Per cent.	Per cent cumulative weights.	Per cent.	Per cent cumulative weights.
No. 10	0.7	0.7	0.2	0.2	0.8	0.8
20	1.4	2.1	2.0	2.2	1.5	2.3
35	7.3	9.4	7.6	9.8	8.6	10.9
65	60.8	70.2	59.9	69.7	56.6	67.5
100	16.2	86.4	15.3	85.0	13.6	81.1
150	3.2	89.6	3.2	88.2	3.1	84.2
200	2.6	92.2	3.1	91.3	3.1	87.3
200	7.8	100.0	8.7	100.0	12.7	100.0
Total	100.0		100.0		100.0	
Permeability	46		45		52	
Moisture, per cent	5.7		6.0		5.9	
Bond, per cent	9.8		10.5		9.2	
Strength, lbs	1.4		1.7		1.4	

easily understood and which presents a reliable picture of the grain distribution of the sand.

26. The grain distribution of a molding sand is responsible for many of its properties. A screen analysis explains many properties which are not revealed in the regular routine testing.

RESEARCH AS BASIS FOR SELECTING SAND

27. When new sands are examined in the laboratory, it is important to be able to foretell to what extent physical properties will change as they are transformed into heap sand. Changes in permeability and strength are not due entirely to burning-out of bond, nor to the addition of auxiliary agents such as sea coal.

28. The efficiency of a sand cannot be exactly known until it is thoroughly incorporated in the heap, because of changes in grain structure caused by working of the heap. Any raw sand consists of glomerates of a number of grains with bond. Hence the true effect of individual grains on the whole is not known until these glomerates are broken up and the material distributed by the working of the heap. Tests which resolve the sand into its chemical or physical elements will remain constant during this transformation.

Grain Residue and Grain Shape

29. From the producer's standpoint, chemical analysis of the grain residue will often determine the locality from which the sand should be taken. For example, sand formed from the decomposition of rock in a sandstone region will have a different composition from that of a deposit formed by glacial action in a shale district.

30. Shape of the grain also helps to determine location of the deposit when one considers the geological processes by which the grains are formed. The rounded grain of a river sand could hardly be expected to be duplicated by a rock-crushing process.

31. When the relation of all the basic elements to the whole is understood, most of these chemical and physical differences can be equalized. It is by balancing these elements that the producer is able to obtain the actual physical properties specified by the foundryman.

32. Take, for instance, the consideration of strength. Factors influencing this property are:

1—Chemical composition of the bond.
2—Amount of bond.
3—Shape of the grain.
4—Grain distribution.

Amount of Bond

33. Chemical composition and the shape of the grain are more or less fixed by the geology of the section in which the sand is found, although the colloidal nature of the bond may vary greatly between pits of the same region. The amount of bond is under control in any sand-blending operation, however, and for this reason the producer considers his bond sand a raw material.

34. The percentage of bond is generally the first consideration when a given strength is specified. A general rule for estimating bond content required in a new sand is to figure on the new sand being from two to five per cent higher in bond than the final result desired in the heap. In order to get a final check on the efficiency of the sand, it is desirable to follow through the effect of this bond content on the strength of the heap sand even after it gets into use.

Grain Distribution

35. The bond sand used in blending consists of colloidal bond and a grain residue. Therefore, the addition of a bond sand to sand of lower bond content modifies the grain structure of the final product.

36. This is the fourth factor which determines the strength of the sand. Its influence on strength is shown by its bearing on the tempering properties of the sand. It was pointed out in a paper before the Pittsburgh Foundrymen's Association[4] that this was very important in regulating most of the physical properties of molding sand. It is here that the producer can be of greatest service to the foundryman.

Comparison of Grain Structures

37. Screen analysis and grain distribution are subjects for basic sand research in the foundry. For any class of casting a grain distribution can be found which gives best results.

38. When the screen analysis is plotted cumulatively on

[4] Kerlin, W. W.—"Screen Analysis Determines Distribution of Sand Grains," *The Foundry*, vol. 58, no. 2, Jan. 15, 1930, pp. 78-80.

the Tyler screen scale, the grain structure of a heap giving good results can be compared with heaps giving inferior results. Such curves are shown in Fig. 2. This method will usually result in the construction of an ideal curve which can be used as a basis of studying sands from various sources.

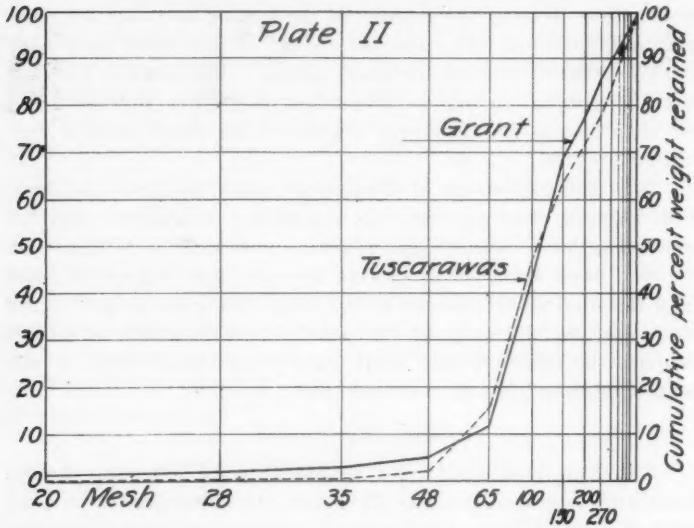

FIG. 2—CUMULATIVE DIRECT DIAGRAM OF SCREEN ANALYSIS ON SAMPLES OF NEW MOLDING SANDS (GRANT AND TUSCARAWAS), TAKEN ON TYLER STANDARD SCREEN SCALE, AT SCREEN SCALE RATIO 1.414. ANALYSIS SHOWS FOLLOWING DATA:

	Grant sand		Tuscarawas sand	
Mesh Size	Per cent.	Per cent cumulative weights.	Per cent.	Per cent cumulative weights.
No. 10	0.3	0.3	...	...
14	0.6	0.9	1.1	1.1
20	0.6	1.5	...	...
28	0.8	2.3	0.1	0.2
35	1.0	3.3	0.2	0.4
48	2.4	5.7	2.0	2.4
65	6.5	12.2	13.3	15.7
100	33.0	45.2	31.6	47.3
150	24.5	69.6	16.7	64.0
200	9.0	78.6	8.6	72.6
270	7.3	85.9	5.8	78.4
Pan	14.1	100.0	21.6	100.0
Total	100.0		100.0	
Permeability, maximum	26		55	
Moisture, per cent	8.0		12.5	
Bond, per cent	17.4		17.9	
Strength, lbs.	1.8		1.2	
Fineness	123		135	

39. When a sand is selected which comes within the grain-size limits desired, and which contains the amount of bond necessary for keeping up the strength of the heaps, the problem of sand control is greatly simplified. The sand control man will then be concerned with checking up shipments of new sand and supervising the regular additions of sand to his heaps every day.

40. One or two sands, carefully chosen, can serve the needs of a foundry producing a wide variety of castings. The advantage of using one sand in a continuous sand-handling system can readily be seen.

Permeability Control

41. In addition to having direct control of strength, the producer controls permeability by properly blending his sands. The most obvious relationship between fineness and permeability, and a general rule which may be followed in regulating permeability, is this: The greater the fineness number, the less the permeability—assuming that the bond content remains constant.

42. This is not always the case, however, as is readily illustrated in Fig. 2. It will be noticed in this case that the sand with the larger fineness number has over twice the permeability of the coarser sand. Since bond content is about the same in both sands, the difference in permeability can be attributed primarily to difference in the grain distribution of the sand. In spite of fineness, these sands would not serve the same purpose in the foundry.

43. When one obtains wide differences in permeability within such a narrow fineness range as is shown in Fig. 2, the remedy usually lies in manipulation of the tempering range of the sand. The maximum permeability of the Tuscarawas sand comes at 12.5 per cent moisture, while the maximum permeability of the Grant sand is at 8.0 per cent moisture. The more uniform grain distribution of the former is denoted by the uniform rise in the curve over the greater part of its length.

44. This difference in grain distribution is probably responsible for retaining more moisture—the surface tension of the film prevents a reduction in strength. Difference in grain shape will also have some effect on permeability, as it probably did to some extent in this example; but tempering qualities are influenced mostly by grain distribution and bond content.

SAND CONTROL BY PRODUCER

45. The facts obtained by basic sand research can best be applied toward sand control by the producer. Familiarity with the sand in his various pits, a knowledge of the effects produced by various combinations and blends, and records of tests and shipments enable a producer to give the foundryman invaluable assistance in his sand control problems.

DISCUSSION

ORAL DISCUSSION

DR. H. RIES:* I agree with Mr. Kerlin as to the chemical analysis in so far as the importance of separating the grain from the run of sand before the chemical analysis is made. Most of us realize that the chemical analysis in the entire sand sample gives us comparatively little information. The chemical analysis of the bond may be important.

The author remarked that the chief constituent of the bond is kaolin. We are hardly warranted in narrowing it down to that. There are comparatively few sands, so far as my experience goes, whose bonding material is what we sometimes call "pure clay." We may have many sands which contain impure clays or bonding material. We may have sand containing a great deal of colloidal iron or colloidal silica in the bond. In other words, the composition of the bond is quite variable.

Regarding the dehydration of the bond, that is an important matter, but the dehydration of the bond is not, of course, always going to take place within the same range of temperature. In other words, it depends upon the constituents of the bond. Some bonds contain constituents which dehydrate at a comparatively low temperature, while in others, the constituents dehydrate at a higher temperature.

Mr. Kerlin states that this matter of dehydration is more important in his opinion, than the actual fusing temperature of the whole sand. It is, I believe, important in connection with the durability or the life of the sand, and that is a point upon which one of the sub-committees of the Sand Test Committee is working at present—the dehydration or the temperature of dehydration of the clay—of the bond. Some bonds dehydrate at much lower temperature than others.

Mr. Kerlin touched on a point of geological interest which may not be of as much interest to the practical foundrymen. It is rather difficult to check up the geological origin of the sand, either by its composition or by the shape of its grains.

I have just finished a study of some 300 sand samples taken from pits all over the United States, and the grain of these sands has been

*Cornell University, Ithaca, N. Y.

rather carefully studied. One interesting point brought out in that investigation is that, regardless of how the sand was formed, the majority of grains are either angular or sub-angular (using the terms the Grading Committee has suggested), and that rounded sand grains are comparatively scarce. When we do find rounded sand grains, they usually are found on the larger screen sizes.

Even though the larger grains of the sand may be well rounded, as soon as you get to the smaller sizes—say, from screen 70 and finer—the grains always show angularity or sub-angularity. There are very few sands which show a uniformly round grain.

H. D. DIETERT:* I presume that the fineness analysis given here is used in plate work. Is that true?

W. W. KERLIN: The fineness is not given in Fig. 1, but that happens to be a boiler sand.

H. W. DIETERT: I cannot agree with you there. The total fine would be rather high, as we would see it, to give us the least amount of spongy iron. We prefer to run the total fines lower than you do.

I agree with you, however, that we would get a better finish if we were to run a sand somewhat as the graph of Fig. 1 shows; but the fines would be considerably lower than what you show. Do you know the loss produced by this sand?

CHAIRMAN O. E. J. ABRAHAMSON:† This sand at the present time runs a loss of about three per cent.

W. W. KERLIN: Regarding Fig. 1, we found that we could reduce the amount of fines in this sand. In other words, we could project this line up closer to the top if, at the same time, we increased the amount of coarse material between 20 and 35 mesh.

If it is desired to make this sand coarser and get less fines in it, the amount of grains in the 20 to 28 and 35-mesh screens must be increased in order to get the ideal curve. In that way a straight line or a line with the same uniform rise would be obtained at the same time, but it would just be projected a little farther to the left of the chart than before.

Therefore, the theory of the uniform rise would hold, although it would just be in a different part of the chart. In fact, that is what was done later when it was desired to increase the permeability of this sand. This line was merely projected a little farther to the left, giving a permeability of about 70 instead of 55.

H. W. DIETERT: In that case, what would be the total material passing 100? Would it be above 25?

W. W. KERLIN: It is less than 25 on the chart.

H. W. DIETERT: What was the total fines when permeability was increased to 70?

W. W. KERLIN: It probably would be decreased to around 15 per cent.

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*U. S. Radiator Corp., Detroit.
†Buffalo, N. Y.

H. W. DIETERT: We feel that if we would give greater study to the total fines, to find some balance of this material with the amount of bond and coarse material, we would have something quite worth while for the foundry in the application of the fineness test.

W. W. KERLIN: I believe permeability is determined more by the amount of fines in the sand than by the coarse particles. To open up this sand, the amount of fines in it would be decreased. At the same time, if a sand which would temper properly were desired, some of the particles in the lower range of this curve would have to be introduced in order to have one to temper properly.

MEMBER: Is there any set rule or formula laid down whereby the permeability of the various kinds of sand and the best strength is obtained to get the best results?

CHAIRMAN O. E. J. ABRAHAMSON: A great deal of work has been done along these lines. In the A. F. A. TRANSACTIONS for 1928, Vol. 36, pp. 34-44, there is a report by Mr. Crane of the Cincinnati University, which shows that permeability and bond will vary greatly for the same class of work within the same city.

There is apparently no relationship between what is being done and what is the proper sand, etc., for different work. Each foundryman will have to establish that for himself. However, those who have investigated sands recommend certain limits. What these limits should be is a very sensitive subject; in telling a man he should run his permeability at a certain definite figure or bond, someone's toes are bound to be stepped on.

W. W. KERLIN: On that same question, permeability is determined in many cases by the surface that is desired on the casting. If one is not so particular about the surface of the casting, the sand can be opened up, keeping in mind the rules laid down by the screen analysis chart I have shown.

If the sand is opened up too much, tempering trouble results. I have found that as long as the uniform rise of the curve of Fig. 1 is kept in mind, the sand can be opened up as much as desired. Then the determining factor is the surface required on the casting.

DR. H. RIES: I would like to add to this discussion that the report of the Sand Reclamation Committee, when it is printed, will contain a number of reports submitted from different foundries. You should find much information in the report as to discretion regarding the range of the different properties used for casting the different metals.

Carbon and Sulphur in the Cupola—Some Properties of Coke

By James T. MacKenzie,* Birmingham, Ala.

Abstract

Data previously presented indicate there is an equilibrium point for total carbon in any given set of cupola conditions, this point being especially dependent on the coke used. Previous literature on this point is reviewed. Sulphur absorption has received a great deal more attention, and the existing literature on this point also is reviewed. Only a few examples of the effect of repeated melting on cast iron have been reported, and the variables existing in the previous work made it desirable to conduct an investigation to add to the fund of knowledge on this subject. Using a No. 0 Whiting cupola, a series of tests were carried out. Six different brands of coke were used, with charges made up of various grades of pig, steel and iron scrap and ferroalloys. An effort was made to have only one variable under each set of conditions. Repeated heats using the same material were run and test data secured. The data tabulated were for changes in per cents of carbon, silicon, manganese and sulphur; brinell hardness; chill depth; temperature and blast variation; modulus of rupture, and modulus of elasticity. The data secured under each set of conditions are discussed thoroughly, and conclusions are drawn.

1. In the paper presented before the Institute of British Foundrymen in 1927,[1] some data were presented (Fig. 1) which indicated that there was an equilibrium point for total carbon in any given set of cupola conditions—being especially dependent on the coke. An old German rule was that any charge under three per cent picked up carbon, and any charge over three per cent lost carbon.

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*Metallurgist, American Cast Iron Pipe Co.

[1] J. T. MacKenzie,, *Some Properties of Coke Affecting the Cupola Melting of Steel.* Proceedings, Institute of British Foundrymen, vol. 20 (1926-27), p. 46.

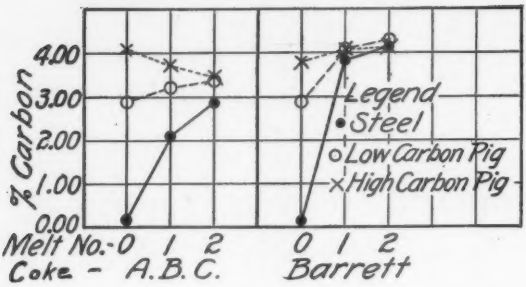

FIG. 1—DATA SHOWING TENDENCY FOR ALL IRONS TO ATTAIN SAME CARBON CONTENT ON REPEATED MELTING. THE AMOUNT IS DEPENDENT ON COKE AND BLAST.

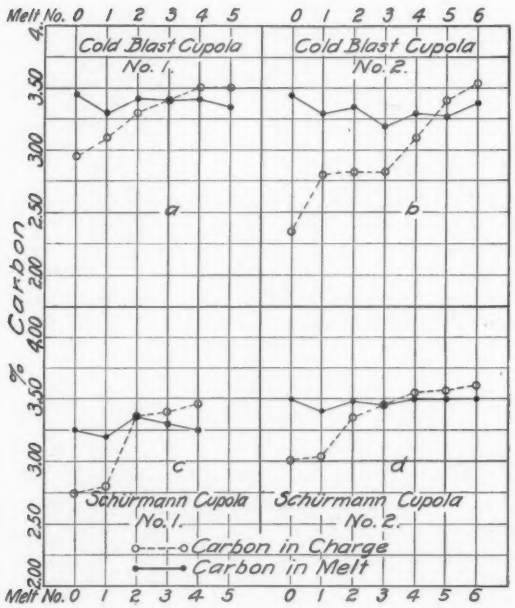
Melt No. 0 1 2 3 4 5 0 1 2 3 4 5 6
Cold Blast Cupola No. 1.
Cold Blast Cupola No. 2.
a
b
% Carbon
c
d
Schürmann Cupola No. 1.
Schürmann Cupola No. 2.
Carbon in Charge
Carbon in Melt
Melt No. 0 1 2 3 4 5 0 1 2 3 4 5 6

FIG. 2—COMPARISON OF CARBON IN METAL CHARGED AND METAL AT SPOUT.—BY PINSL (DIE GIESSEREI, P. 1294, 1928).

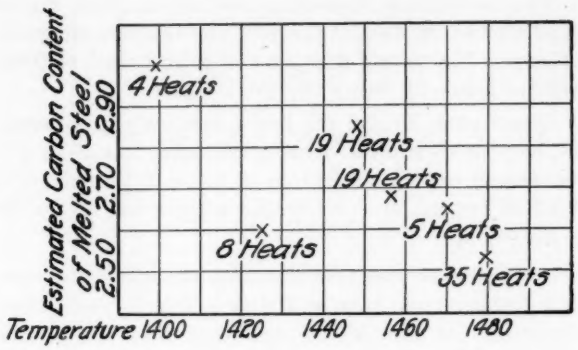

FIG. 3—CARBON ABSORPTION TEMPERATURE. THE ESTIMATED CARBON CONTENT IS CALCULATED FROM THE CARBON CONTENT OF THE CHARGE, THAT OF THE MELT AND THE PERCENTAGE OF STEEL IN THE CHARGE.—BY LORINSER.

2. Most references in the literature, following Osann, state that steel will carburize to about 2.7 per cent, although some have found higher values. Gilles[2] states that 70 per cent steel mixtures give 2.5 to 3.0 per cent carbon, but later in the same volume[3] he states that the normal process (referring, probably, to ordinary mixtures) gives 3.4 to 3.6 per cent carbon.

3. Klingenstein, as quoted by Gilles, reports that wrought scrap gives 3.1 to 3.2 per cent C. Pinsl[4] actually gives results (plotted in Fig. 2) showing practical equilibrium in one melt where the charge is not over one per cent from the point. He shows no melts of high-carbon material, and the results are not corrected for differences in the other metalloids, which have a considerable influence. Pinsl gives a great many experiments which are too detailed to be summarized here.

4. Lorinser[5] shows results from ninety melts, varying from 40 to 60 per cent steel. His results are interesting and are reproduced in Fig. 3, which shows the apparent reduction of carbon absorbed with increasing temperature of the melt.

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[2] Chr. Gilles, *Die Erzeugung von Gusseisen Hoher Festigkeit.* Giesserei Zeitung, vol. 23, no. 8 (Apr., 1926), p. 203.

[3] Chr. Gilles, *Das Interesse des Eisengiessers an der Frage der Direkten Eisenerzeugung.* Giesserei Zeitung, vol. 23, no. 21 (Nov., 1926), p. 587.

[4] H. Pinsl, *Beitrag zur Frage der Kohlenstoffveränderung während der Kupolofenschmelzung.* Die Giesserei, vol. 15, no. 52 (Dec., 1928), p. 1292.

[5] P. Lorinser, *Zur Frage der Aufkohlung von Stahlschrott im Kupelofen.* Die Giesserei, vol. 15, no. 16 (Apr., 1928), p. 366.

5. The "estimated carbon" is calculated from the carbon content of the charge, that of the melt and the percentage of steel in the charge. The points represent average values of from four to thirty-five heats, as indicated in the figure.

6. Pinsl[4] gives by far the best summary of the work done to 1928, but his own tests contain too many variables to solve the problems of carbon absorption in relation to blast, temperature, kind of cupola, etc. As to the coke, Pinsl makes the following statement:

> "It is to be assumed that both the speed and ease of solution of the coke will play a role in the carbon absorption in the cupola, and that these properties will vary with different cokes. Investigations on that subject are scarcely known."

7. Piwowarsky, in his book "Hochwertiger Grauguss," published in 1929, made no reference to the subject other than the present writer's paper of 1927. Williams[6] investigated the effect of different forms of carbon as electric-furnace carburizers, but the comparative values in the cupola probably will be greatly influenced by factors other than those influencing electric-furnace carburization.

8. Sulphur absorption has received a great deal more attention. Osann long ago made the generalization that, with ordinary charges, 30 per cent of the coke sulphur is absorbed by the iron and 25 per cent of the sulphur in the iron is lost to the slag. This, of course, would indicate an equilibrium when these two percentages give the same amount of sulphur.

9. For example, using 10 per cent of coke containing one per cent sulphur, the sulphur in the iron would not be affected by melting if the charge analyzed 0.12 per cent S. Walter[7] brought out the point that the lower the sulphur in the charge, the greater would be the absorption; but he curiously overlooked the effect of the amount of sulphur in the coke, although Schultz brought out this point in the discussion of Walter's paper.

10. Schultz[8] showed the effect of manganese in the sulphur

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[6] C. E. Williams and C. E. Simms, *Electric-Furnace Cast Iron*. Technical paper No. 418, U. S. Bureau of Mines.

[7] R. Walter, *Increase of Sulphur in Cupola*. Giesserei Zeitung, vol. 19, No. 34 (1922), p. 492.

[8] Schultz, *Manganese and Sulphur*. Giesserei Zeitung, vol. 17, p. 291.

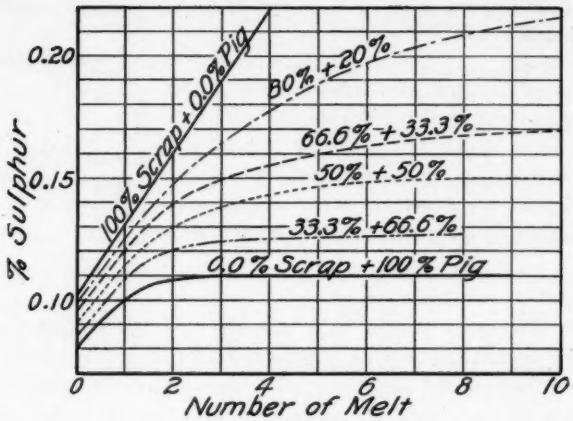

FIG. 4—THE INFLUENCE OF REPEATED MELTING ON THE SULPHUR CONTENT OF MOLTEN IRON.—J. E. FLETCHER. (GRAY IRON: 0.03 SULPHUR IN PIG; 0.10 SULPHUR IN FIRST SCRAP.)

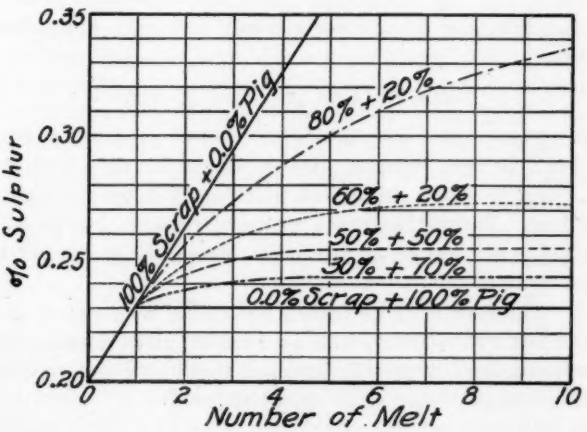

FIG. 5—THE INFLUENCE OF REPEATED MELTING ON THE SULPHUR CONTENT OF MOLTEN IRON.—J. E. FLETCHER. (WHITE IRON: 0.2 SULPHUR IN PIG; 0.23 SULPHUR IN FIRST SCRAP.)

content of cupola iron in a series of tests, part of which are given below:

Manganese	Sulphur
0.68	0.080
0.82	0.068
0.86	0.062
0.97	0.056
1.02	0.052
1.02	0.059
1.04	0.060

11. Fletcher[9] stated that sulphur attains equilibrium in ordinary conditions where a foundry is using a constant percentage of scrap and pig, the equilibrium point depending on the character of the scrap, the sulphur content of the coke and the sulphur and manganese content of the pig. He also points out that steel scrap or other low-carbon material shows high sulphur absorption.

12. Piwowarsky[10] shows some results by Fletcher as published in a report to the B. C. I. R. A., which was not available to the present writer. The graphs as given are shown in Figs. 4 and 5. Not having the original, it is difficult to comment on the exact shape of the lines; but they seem essentially rational, assuming that the manganese content was held approximately constant.

Little Data on Repeated Melting

13. Some few examples of the effect of repeated melting on cast iron have been reported, the pioneer in the field undoubtedly being Percy,[11] whose analytical aides seemed not to have been of the best. Turner[12] shows a series of remelts, but he allowed all elements to change, so that the results are of no particular interest to the modern foundryman.

14. The results of Fletcher's tests have been shown in Figs. 4 and 5; but Piwowarsky, who quotes him, gives nothing but the sulphur, although it may be assumed that the cupola conditions and coke remained the same in all the melts.

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[9] J. E. Fletcher, *Utilization of Scrap in the Foundry.* Bulletin B. C. I. R. A., Jan., 1925.

[10] E. Piwowarsky, *Hochwertiger Grauguss.* Springer, Berlin, 1929, p. 106.

[11] Percy, *Metallurgy of Iron and Steel.* Murray, London, 1864, p. 868.

[12] T. Turner, *The Metallurgy of Iron.* Griffin, London, 6th edition, 1920, p. 297.

METHOD OF CONDUCTING INVESTIGATION

Cupola Details

15. The tests which are presented in this paper were all made in a No. 0 Whiting cupola, which has two tuyeres, a 27 in. shell and an over-all height of 7½ feet. It was lined to 18 in. and maintained cylindrical by daily daubing. The bed was well burned to a point some two or three inches below that desired, and fresh coke added to bring to height just before charging.

Charges

16. Charges were kept at 120 lbs. in all the tests. Pig and low-grade ferrosilicon as well as coke were weighed on a grocery scale accurate to one-half pound. High-grade alloys were weighed on a laboratory scale to one-half ounce and charged tightly wrapped in paper bags.

17. The cupola held from four to five charges when first filled, and two more usually could be added before melting began. About ten inches of coke were added after the last charge was in.

Blast

18. Blast was put on for ten minutes with the tap hole open and the cupola full. It was then cut off, the tap hole plugged with dry blacking (coke dust) and blowing resumed in the customary manner. The fan used for a blower was a small one and the bearing wore out several times during the tests. After considerable difficulty, it was rebuilt and then gave nine ounces' pressure as against six ounces from the original set-up.

19. This, unfortunately, produced another variable in the test and we have grouped them accordingly. As the difference in volume delivered is not very great (less than 22 per cent) it would not be expected to make much difference in the results; and if it did, the difference is quite obscured in other variables.

Melting and Pouring Losses

20. In case of the steel melts, the ladle was preheated to a bright red—even then, considerable trouble from skulling was encountered with the low carbons. Most of the tests began with 15 charges, although some few were run on less, and one on more.

21. The loss in melting, pouring, and especially that due to the withdrawal of samples, reduced this by approximately

100 lbs. per melt, and the test was discontinued when less than 500 lbs. was left, as such a small amount does not give consistent results.

Checking Temperatures

22. Temperatures were read with a Leeds & Northrup optical pyrometer of the disappearing filament type. The instrument was standardized by the Bureau of Standards when about half way through the tests, and as these values check closely with the original certificate furnished by the manufacturers, in all probability it was correct throughout.

23. Corrections were made for true temperatures of the molten iron by the curve shown in Fig. 5 of Wensel and Roeser's paper on the subject.[13] Corrected values should be within 25 degs. Cent. of the true temperature and are probably closer than that, say, within 10 degs. Cent.

Chemical Analyses

24. The analyses given in the tables and figures are all averaged from the test-bar analyses. Three test bars and two chilled test pieces were poured from two or more ladles of each heat.

25. In case of the pig melts, when little variation was expected, only three or four ladles were sampled. When the original melts were made on steel with heavy alloy additions, from five to seven ladles were sampled. On the second melt we took three sets of samples, and this was repeated on the third if there was much variation. On the fourth and succeeding melts we sampled two consecutive ladles in the middle of the heat.

26. This method of sampling has produced some inaccuracy, which may be noted in the incongruous shape of some of the curves—especially on the first and second melt; but it is of rather small order, and the work could never have been done had it been necessary to analyze every ladle, for the analytical labor has been tremendous as it is.

Order of Procedure

27. To illustrate the order of procedure, to show the weights of the ladles and to indicate the variations and possible errors involved, four heats are shown in Tables 1 to 4, inclusive,

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[13] Wensel and Roeser, *Temperature Measurements of Molten Cast Iron*. TRANS. A. F. A., vol. 36 (1928), p. 191

Table 1

MIXTURE AND MELTING DATA FOR TESTS OF PITCH COKE (12½%), STEEL SCRAP AND RUSTLESS FERROSILICON COMBINATION

(1 Heat, 7 Taps)

(Charge: 95 lbs. Steel Scrap; 25 lbs. Rustless 15% Ferrosilicon; 1 lb. 80% Ferromanganese)

Tap No.	Poured into.	Wt., lbs.	Silicon, per cent.	Silicon, lbs.	Mn, per cent.	Mn, lbs.	Carbon, per cent.
1	Pigs	148	3.14	4.65	1.00	1.48	....
2	Bars	152	2.80	4.26	.81	1.23	3.46
3	Bars	155	2.94	4.56	.99	1.53	3.34
4	Bars	155	2.97	4.60	.77	1.19	3.30
5	Bars	157	2.85	4.47	.80	1.26	3.26
6	Bars	159	2.58	4.11	.75	1.19	3.38
7	Pigs	39	2.68	1.05	.71	.29	....
Total		965		27.70		8.17	
True avg.....			2.87		.85		

Total charged, 978.5 lbs.

Melting loss, 13.5 lbs., 1.4 per cent.

Table 2

MIXTURE AND MELTING DATA FOR TESTS OF PITCH COKE (12½%), STEEL SCRAP AND RUSTED FERROSILICON COMBINATION

(1 Heat, 8 Taps)

(Charge: 95 lbs. Steel Scrap; 25 lbs. Rusted 15% Ferrosilicon; 1 lb. 80% Ferromanganese)

Tap No.	Poured into.	Wt., lbs.	Silicon, per cent.	Silicon, lbs.	Mn, per cent.	Mn, lbs.	Carbon per cent.	Carbon, lbs.
1	Pigs	53	2.01	1.06	.75	.40	3.58	1.95
2	Pigs	80	2.33	1.86	.93	.74	3.59	2.95
3	Bars	125	2.35	2.94	1.01	1.26	3.74	4.68
4	Bars	115	2.50	2.88	.95	1.09	3.68	4.23
5	Bars	149	2.37	3.54	.90	1.34	3.62	5.39
6	Bars	156	2.31	3.60	1.01	1.57	3.51	5.48
7	Bars	156	2.67	4.16	.85	1.33	3.16	4.93
8	Pigs	120	2.98	3.58	.83	1.00	3.20	3.84
Total		954		23.62		8.73		33.45
True avg.....			2.48		.92		3.51	

Total charged, 978.5 lbs.

Melting loss, 24.5 lbs., 2.5 per cent.

each tap from which was analyzed for silicon, manganese and carbon. Sulphur was not run, as it is so frequently different in the pig samples from that in the test bars. The silicon is the most important variable, as the steel contains practically none; thus all of it is derived from the ferroalloy, which contained approximately 15 per cent silicon and three per cent titanium.

28. Table 1 shows a heat with the part of the shipment of silicon that was still unspotted by rust after months of exposure to the weather. Table 2 was identical, except that lumps were selected which had rusted considerably under the same exposure —in fact, both lots came in the same car and were on the same pile in the yard. They also showed the same silicon and titanium content by the conventional methods of analysis.

29. It is obvious that some of both elements in the rusted material were present as unreduced oxides instead of in the metallic state as in the bright stuff. These two heats were combined as melt No. 1 in Table 10.

30. Table 3 shows all the taps of another heat. There is a curious drop in silicon in the middle of the heat which we are unable to explain. This heat is melt number 1 in Table 11.

Table 3

MIXTURE AND MELTING DATA FOR TESTS OF *A. B.* COKE (12½%), STEEL SCRAP, FERROSILICON AND FERROMANGANESE COMBINATION

(1 Heat, 11 Taps)

(Charge: 95 lbs. Steel Scrap; 25 lbs. 15% Ferrosilicon; 1 lb. 80% Ferromanganese)

Tap No.	Poured into.	Wt., lbs.	Silicon, per cent.	Silicon, lbs.	Mn, per cent.	Mn, lbs.	Carbon per cent.	Carbon, lbs.
1	Pigs	162	3.18	5.15	1.16	1.88	2.34	3.79
2	Bars	163	3.11	5.08	.84	1.37	2.27	3.70
3	Bars	130	2.91	3.78	.43	.56	2.27	2.95
4	Pigs	125	3.32	4.15	.97	1.21	2.39	2.99
5	Bars	124	2.51	3.12	1.63	2.02	2.54	3.15
6	Bars	137	1.06	1.45	.54	.74	2.72	3.73
7	Bars	138	1.86	2.56	.53	.73	2.55	3.52
8	Bars	143	2.10	3.00	.96	1.37	2.36	3.38
9	Pigs	141	3.25	4.57	.80	1.13	1.89	2.67
10	Pigs	107	3.49	3.73	.68	.73	1.78	1.90
11	Pigs	26	3.49	.91	.52	.14	2.04	.53
Total		1396		37.50		11.98		32.31
True avg.			2.68		.86		2.31	

Total charged, 1452 lbs.

Melting loss, 56 lbs., 3.9 per cent.

Table 4

MIXTURE AND MELTING DATA FOR TESTS OF *R.H.* COKE (12½%), STEEL SCRAP, FERROSILICON AND FERROMANGANESE COMBINATION

(1 Heat, 15 Taps)

(Charge: 95 lbs. Steel Scrap; 25 lbs. 15% Ferrosilicon; 1 lb. 80% Ferromanganese)

Tap No.	Poured into.	Wt., lbs.	Silicon, per cent.	Silicon, lbs.	Mn, per cent.	Mn, lbs.	Carbon per cent.	Carbon, lbs.
1	Pigs	58	4.82	2.80	1.54	.89	1.69	.98
2	Pigs	37	2.42	.89	1.13	.42	1.93	.72
3	Pigs	39	3.70	1.44	1.24	.48	1.65	.64
4	Pigs	81	2.22	1.80	.55	.44	1.89	1.53
5	Pigs	123	2.30	2.83	1.00	1.23	2.02	2.48
6	Bars	137	2.27	3.10	.89	1.22	1.93	2.65
7	Bars	143	2.19	3.13	.53	.76	1.89	2.70
8	Pigs	117	....	....	Sample Lost		....	....
9	Bars	142	3.10	4.40	1.10	1.56	1.91	2.71
10	Bars	139	2.44	3.39	.92	1.28	1.62	2.25
11	Bars	132	2.48	3.28	.65	.86	1.63	2.15
12	Bars	132	2.14	2.83	.59	.78	1.56	2.06
13	Bars	148	2.20	3.26	.79	1.17	1.70	2.52
14	Pigs	146	3.15	4.60	.79	1.15	1.44	2.10
15	Pigs	118	3.24	3.82	.81	.96	1.62	1.91
Total (excl. No. 8).....		1575		41.57		13.18		27.40
True avg.....			2.64		.85		1.74	

Total charged, 1815 lbs.

Melting loss, 123 lbs., 6.8 per cent.

Table 5

PHYSICAL AND CHEMICAL DATA ON COKES USED IN INVESTIGATION

Symbol	Kind	Temp. of Ignition, Degrees Fahr.** Min.	Max.	Avg.	Minutes for 250-deg. Fahr. rise**	Max. temp. rise, degs. Fahr.**	Shatter‡	Cell space‡	Ash, per cent	Volatile, matter, per cent	Sulphur, per cent
R.H.	Special*	.....	.....	.....	...	...	69	49	13.6	.8	1.0
R.B.	Furnace*	1,045	1,120	1,085	2.6	256	63	49	14.6	1.3	0.9
W.B.	Furnace*	960	1,030	992	2.4	269	70	54	9.6	1.8	1.0
A.B.	Foundry*	1,055	1,155	1,095	2.9	241	73	49	10.0	.8	.6
Q.B.	Pitch†	920	1,000	964	1.4	350	88	47	.4	.9	.4
H.C.	Foundry†	940	1,060	1,005	2.6	259	79	59	10.2	1.0	.7

*By-P.—By-product oven.

†B.H.—Beehive oven.

**Boegehold burning test.

‡A. S. T. M. tests.

Table 4 is melt number 1 in Table 9. It also shows large variations in silicon and manganese.

31. The difference between the average of all the test bars and the true average for the melt is indicated in the figures accompanying the respective tables. Only the averages from the test bars are given in Tables 6 to 19, inclusive, but after the second heat the error probably is small indeed.

Analytical Procedures

32. The analytical procedure was essentially that of the standard A. S. T. M. methods for the chemical analysis of cast iron. A noteworthy exception was that it was necessary to introduce an auxiliary absorbent in the carbon train for sulphurs of 0.15 or over.

33. This was called to our attention by Dr. G. E. F. Lundell of the Bureau of Standards. The absorbent recommended by him was a 50-per cent aqueous solution of chromic trioxide. Differences as high as 0.35 per cent carbon were found on some of the very high sulphurs (0.4 and over).

34. Manganese was run by the routine persulphate method and checked by the improved method reported by Bright and Larrabee,[14] which we found both rapid and accurate.

35. Only the results of the gravimetric method for sulphur are reported in the paper. Evolution sulphur was run as a check, and in case of unusual variation, one or both methods were checked until we were reasonably sure of the sulphur content.

36. Silicons were run on one-gram samples and checked at least once. When failing to check within 0.04 per cent, they were re-run. The gram sample gives results which are usually 0.02 per cent lower than the true value, but the results in the paper are not corrected for this slight error.

37. Carbon was run twice if low, and three times if high. In case of failure to check within 0.04 per cent, it was re-run until we were reasonably sure of the carbon. High graphite, such as was obtained with the later melts of *Q.B.* coke, made the carbon determination extraordinarily difficult, and we made as many as twelve determinations before we felt sure of the carbon on some of the samples.

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[14] Bright and Larrabee, *Determination of Manganese in Steel and Iron by the Persulphate-Arsenate Method.* Bur. of Stds. Jnl. of Research, vol. 3, no. 4 (Oct., 1929), p. 573.

Degree of Accuracy

38. Inasmuch as all values in the tables, except two or three, are averages of two or more samples, the following statement of accuracy is justified:

Carbon,	±	(0.02 % C + 1% of carbon of sample)
Silicon,	±	(0.02 % Si + 2% of silicon of sample) + 0.02% Si
Manganese,	±	(0.02 % Mn + 4% of manganese of sample)
Sulphur	±	(0.002% S + 1% of sulphur of sample)
Phosphorus,	±	(0.02 % P + 2% of phosphorus of sample)
Titanium,	±	(0.01 % Ti + 10% of titanium of sample)

Test Bars

39. The test bars were the standard of the A. S. T. M. for cast-iron pipe (2 in. x 1 in. x 26 in. broken flatwise on 24-in. supports). The results for strength are given as modulus of rupture in thousands of pounds per square inch. This is approximately twenty times the breaking load of the present arbitration bar (1.20 in. diam. on 18-in. supports); eighteen times that of the pipe bar, and twelve times that of the old arbitration bar (1.25 in. diam. on 12-in. supports).

40. The modulus of elasticity, stated in millions of pounds per square inch, might more properly be called the stiffness ratio, and is a direct index of the stiffness. The modulus of elasticity of the pipe bar and the new arbitration bar are very nearly the same, with the old bar showing roughly three-fourths as high. The comparisons on these three bars are worked out experimentally in some detail in a paper presented to the A. S. T. M. in 1926.[15]

41. Brinell values are the average of five readings on one bar from each set. On the cross-section, one reading was taken at the center, one as close as possible to the corner and one half way between these two; then on the one-inch side, the middle and as close as possible to the edge.

Chill Tests

42. Two chilled tests were poured, one 1½ x 1½ x 6 in., the other 3 x 1½ x 6 in. The 1½ x 6 in. face was against the chill in both cases.

43. The results given are the averages of all the chills in a

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[15] J. T. MacKenzie, *A Note on the Relations Between the Proposed Standard Test Bar for Cast Iron and the Two Existing Standards.* Proceedings, A. S. T. M., vol. 26 (1926), p. 177.

set, except where the small chill was white throughout when only the large one was used. The extra thickness of the large chill seems to have very little effect on the depth of chill. Measurements were made with a depth gauge to the first gray speck and to the last white speck, about half way between the middle and edge of the contact line.

Cokes Used

44. The cokes used are listed in Table 5. This shows all the obtainable data, including the Boegehold burning test,[16] which gives ignition temperature, temperature rise (both in degrees Fahr.) and time for 250-degree rise in minutes. Mr. Boegehold very kindly had these tests run in his own laboratory for us.

45. The other data were obtained by A. S. T. M. standard procedure. Cokes *R.H.* and *A.B.* were made in ovens producing foundry by-product coke. *R.H.* was from a mixture of coal made especially for us by W. E. Curran of the Republic Iron & Steel Co., Birmingham, Ala., as it seemed impossible to find a foundry coke of such analysis.

46. We endeavored to get 1.2 per cent sulphur, but failed by 0.2 per cent—which is regrettable, as it would have made a most interesting extension of the sulphur curves. Cokes *Q.B.* and *H.C.* are made in beehive ovens, *Q.B.* being pitch coke and *H.C.* from Pennsylvania. *R.B.* and *W.B.* are both blast-furnace cokes which are regularly produced in the Birmingham district of Alabama.

DISCUSSION OF TEST RESULTS

47. Tables 6 to 19 and the corresponding Figs. 6 to 19, inclusive, show the results of the several series of melts in detail. Only the averages of the two chill tests are plotted in the figures. Alloy additions are indicated just to the right of the melt line which produced the material to which they were added.

TESTS USING 12½% COKE, 6 OZ. BLAST AND 3% DOLOMITE

48. Tables 6 to 11 and the corresponding Figs. 6 to 11, inclusive, are all tests with 12½ per cent coke and approximately six ounces blast, slagged with three per cent dolomite.

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[16] A. L. Boegehold, *Quality of Pig Iron and Castings as Affected by Blast-Furnace Practice.* TRANS. A. F. A., vol. 37 (1929), p. 91.

High-Sulphur Pig

49. Table 6 and Fig. 6 show a test of high sulphur pig without alloy addition or slag. Although the sulphur fell a little on each melt, so did the carbon and silicon, and it became so wild that the metal was impossible to handle on the third melt. After blowing an hour on this heat without being able to open the tap hole, we finally succeeded in knocking out the whole breast, which deluged us with molten iron; all but one ladle was lost, which was cast into pigs for the much-desired sample.

Coke R.H. with High-Sulphur Pig

50. Table 7 and Fig. 7 show a melt of the same high sulphur pig with the special coke *R.H.* Here we added both silicon and manganese rapidly until they reached 3 per cent and 1 per cent, respectively, thus reducing the sulphur from 0.97 to 0.127 and the chill from 3.00 in. to 0.07 in. The metal was melted again without alloy, whereupon the sulphur and chill rose rapidly after the manganese dropped below 0.40.

51. A small addition of manganese on heat No. 11 halted the chill but failed to stop the sulphur. The carbon rose slowly to 3.15 per cent but fell back when the sulphur went up again. The abrupt change of strength on 10 and 12 (the low manganese) is noteworthy, these being lower than No. 1, which had much higher sulphur.

52. The stiffness increased sharply on No. 12, as did the brinell and the chill. Another sample poured from No. 12 after two minutes standing in the ladle showed 0.230 sulphur, but not much drop was expected on account of the low manganese and carbon.

Coke Q.B. with High-Sulphur Pig

53. Table 8 and Fig. 8 show nine melts of the same pig with pitch coke *Q.B.* There was not enough left to run twelve heats as desired. Here the carbon, after a slow start, reached saturation on the sixth melt. Sulphur dropped steadily to 0.06 on the seventh melt, after which it remained practically constant. The chill dropped with extreme rapidity in the first three melts, as did the stiffness and hardness. The total carbon on these last melts depended on how quickly the molds were poured. On the pigs, kish was sometimes an inch thick.

Table 6

DATA ON REPEATED MELTS WITH CHARGES OF *A. B.* COKE (12½%) AND HIGH-SULPHUR PIG, USING 34-INCH BED AND NO FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill: Last white.	Chill: First gray.	Chill: Brinell.	Mod. of rupture.	Mod. of elasticity.
Orig.	..	..	..	....	2.55	.97	.970	.10	.85	.01	...	...	...	...	...
1	.00	.00	5.8	1410	2.37	.87	.830	.05	.93	..	3.00	3.00	372	41.9	20.6
2	.00	.00	5.8	1453	2.28	.66	.813	.06	.94	..	3.00	3.00	365	43.4	21.4
3	.00	.00	5.8	N.R.	2.03	.54	.800	.06	N.D.		——Too cold to cast bars——				

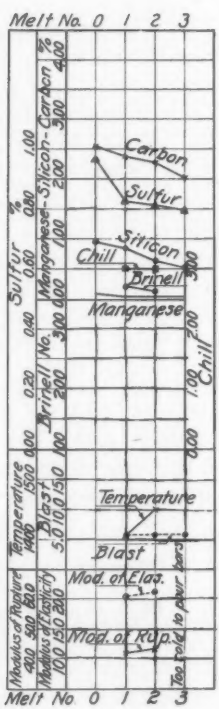

FIG. 6—EFFECT OF REPEATED MELTING. (SEE TABLE 6.)
HIGH-SULPHUR PIG (PHOS. 0.85—NO FLUX—34-IN. BED.
12½% *A. B.* COKE (BY-PRODUCT COKE—10% ASH—0.6 SULPHUR).
AS THE TAP HOLE FROZE ON THIRD MELT, TEST BARS COULD NOT BE POURED.

Table 7

DATA ON REPEATED MELTS WITH CHARGES OF *R. H. COKE* (12½%) AND HIGH SULPHUR PIG, USING 34-INCH BED AND 3% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill—Last white.	Chill—First gray.	Brinell.	Mod. of rupture.	Mod. of elasticity.
Orig.	..	...	...	....	2.55	.97	.970	.10	.85	...	...	...	...	....	....
1	2.00	.80	6.6	1506	2.52	2.13	.431	.49	.85	.03	2.26	2.26	351	42.4	19.3
2	.63	.32	7.0	1482	2.23	2.56	.328	.49	.84	.02	1.82	1.82	325	42.2	18.2
3	.62	.40	6.7	1467	2.38	3.01	.180	.80	.84	...	.08	.04	281	56.4	17.7
4	.25	.40	6.1	1467	2.48	2.79	.212	.73	.84	...	.21	.15	278	54.0	17.8
5	.25	.40	6.0	1465	2.52	2.77	.185	.92	.84	...	.15	.09	269	55.4	17.7
6	.25	.40	6.1	1459	2.69	2.82	.127	1.17	.86	.02	.09	.06	266	52.8	17.2
7	.00	.00	5.7	1465	2.78	2.84	.142	.70	.84	...	.11	.06	263	53.3	16.5
8	.00	.00	4.9	1448	2.87	2.65	.135	.50	.85	...	.09	.06	253	54.2	15.2
9	.00	.00	6.4	1465	2.95	2.52	.145	.42	.86	...	.08	.07	258	56.2	14.7
10	.00	.00	5.5	1430	2.89	2.36	.191	.31	.83	...	.42	.41	281	46.3	15.2
11	.00	.16	6.4	1434	2.82	2.13	.230	.40	.84	...	.44	.43	297	50.4	15.8
12	.00	.00	6.4	1422	2.75	1.91	.246	.29	.85	.02	1.48	1.47	351	37.8	21.0

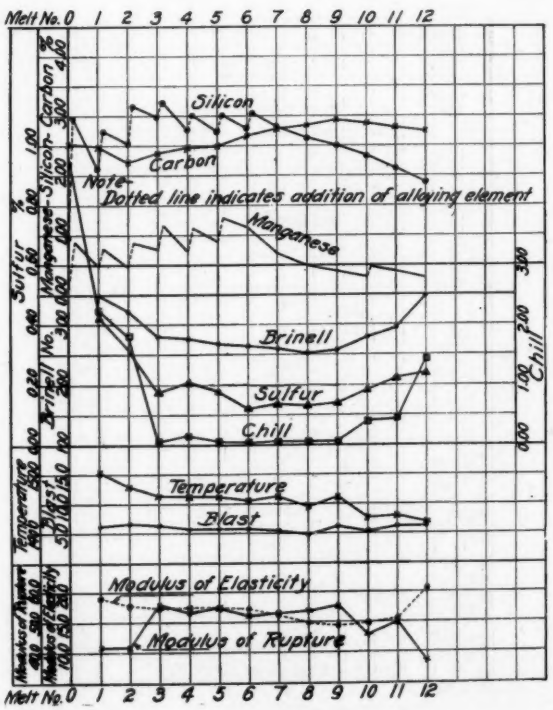

FIG. 7—EFFECT OF REPEATED MELTING. (SEE TABLE 7.)

Table 8

DATA ON REPEATED MELTS WITH CHARGES OF *Q. B.* PITCH COKE (12½%) AND HIGH SULPHUR PIG, USING 34-INCH BED AND 3% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill—Last white.	Chill—First gray.	Brinell.	Mod. of rupture.	Mod. of elasticity.
Orig.	..	...	...	....	2.55	.97	.970	.10	.85	...	...	...	...	....	....
1	1.00	1.00	N.R.	1518	2.58	1.70	.461	.39	.85	.01	3.00	3.00	398	38.2	19.8
2	.50	.40	6.9	1546	3.17	1.78	.430	.41	.87	...	.84	.84	273	32.7	15.5
3	.50	.40	6.1	1563	3.31	1.91	.296	.47	.84	...	.05	.05	251	48.9	12.6
4	.25	.40	6.0	1514	3.55	1.79	.198	.57	.89	.01	.02	.02	219	45.2	11.2
5	.25	.40	5.7	1471	3.57	1.84	.130	.73	.88	...	.01	.01	202	39.4	10.8
6	.25	.40	6.0	1446	3.74	1.81	.084	.73	.86	...	.00	.00	193	40.7	9.7
7	.25	.40	6.1	1459	3.80	1.83	.064	.97	.85	...	.01	.00	184	40.0	9.7
8	.25	.00	6.4	1472	3.91	1.82	.059	.73	.88	...	.00	.00	185	38.0	8.6
9	.25	.00	6.4	1467	3.91	1.93	.065	.63	.87	...	.00	.00	189	40.5	8.8

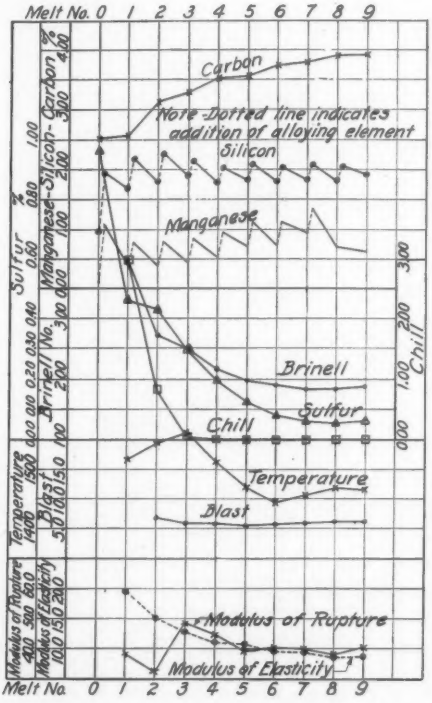

FIG. 8—EFFECT OF REPEATED MELTING. (SEE TABLE 8.)

Table 9

DATA ON REPEATED MELTS WITH CHARGES OF *R. H.* COKE (12½%) AND STEEL, USING 34-INCH BED AND 3% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill—Last white.	Chill—First gray.	Brinell.	Mod. of rupture.	Mod. of elasticity.
Orig.	2.90	.80	...	....	.40	3.08	.045	1.12	.20	.45	...	...	...	....	....
1	.00	.00	6.4	1503	1.74	2.40*	.146	.78	.20	.07	1.56	.95	288	58.6	20.8
2	.00	.00	7.3	1463	2.31	2.47	.198	.68	.20	.04	.14	.06	260	61.0	18.0
3	.00	.00	7.0	1468	2.45	2.53	.218	.54	.21	.04	.15	.10	257	65.8	17.5
4	.00	.00	6.7	1504	2.64	2.40	.249	.44	.25	.03	1.13	1.13	268	47.8	14.2
5	.00	.00	6.4	1470	2.65	2.33	.285	.38	.27	.01	3.00	3.00	413	43.7	20.7
6	.00	.32	6.4	1485	2.74	2.20	.268	.63	.27	...	1.05	1.04	295	49.9	17.0
7	.00	.16	5.8	1472	2.76	2.07	.253	.52	.27	...	.30	.24	263	66.7	15.3
8	.00	.16	5.8	1461	2.80	1.90	.278	.45	.27	...	.83	.76	307	51.5	16.0
9	.00	.16	5.2	1475	2.85	1.81	.279	.41	.29	...	1.90	1.26	302	37.5	16.5
10	.00	.32	5.2	1475	2.81	1.74	.253	.52	.30	...	.84	.64	267	62.3	17.1
11	.00	.32	5.2	1472	2.99	1.59	.195	.79	.30	...	.46	.37	246	63.0	15.0

*Weighted average all taps gives 2.64 Si, 0.84 Mn.

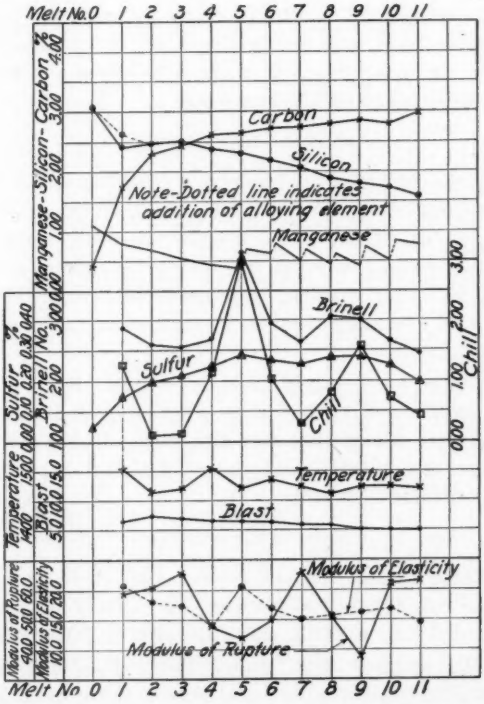

FIG. 9—EFFECT OF REPEATED MELTING. (SEE TABLE 9.)

Coke R.H. with Steel

54. Table 9 and Fig. 9 give a test of coke *R.H.* with steel. The steel melts were all made on a charge of 95 lbs. steel scrap—section averaging ¾ in. round to 1¼ in. round—25 lbs. of ferro-silicon (15 per cent as previously described) and one pound 80 per cent ferromanganese.

55. On this test silicon was allowed to fall steadily. Carbon came to 1.74 on the first melt and slowly rose to a stop at 2.80, except for a sudden rise on the last heat when the manganese was considerably raised. Sulphur rose with falling manganese to 0.285 in melt No. 6, when resumption of ferromanganese drove it slowly back to 0.195 at the end of the test.

56. The carbon is the principal factor of the physical properties on the first three melts, but after that the influence of the sulphur and manganese are predominant. The high chill, hardness and stiffness on melt No. 5 were severely reduced by manganese addition, but climbed back as the manganese fell to 0.41 on No. 10 and again fell when double manganese addition overcame the sulphur on the last heats.

Pitch Coke and Steel

57. Table 10 and Fig. 10 show a steel melt (all steel melts the same initial charge) with pitch coke *Q.B.* For the operator, this test gave nine races to see whether the iron could be poured before the graphite got out of it. It was saturated with carbon on the fourth melt. Silicon and manganese were both allowed to drop—with the exception of a small manganese addition on melt No. 3.

58. The sulphur stayed fairly constant after reaching 0.07 until the manganese reached 0.40, whereupon it rose steadily to 0.119; this, with 0.24 manganese and only 1.25 silicon, succeeded in showing a slight chill in spite of 4.34 per cent carbon and consequent primary graphite.

Coke A.B. and Steel

59. Table 11 and Fig. 11 show a steel melt with coke *A.B.* Carbon rose rapidly to 3.00 per cent and slowly to 3.50 per cent, with a decided halt at 3.35, while the silicon fell steadily.

60. The sulphur and manganese curves are interesting. Sulphur rose steadily to 0.135 and stayed there until the manganese fell to 0.32, then jumped to 0.177 in three heats in spite of

Table 10

DATA ON REPEATED MELTS WITH CHARGES OF *Q. B.* PITCH COKE (12½%) AND STEEL, USING 34-INCH BED AND 3% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill—Last white.	Chill—First gray.	Brinell.	Mod. rupture.	Mod. elasticity.
Orig.	3.00	.80	...	....	.40	3.08	.045	1.12	.20	.45	...	...	...	....	....
1	...	...	6.3	1510	3.45	2.63*	.077	.88	.20	.15	.04	.02	194	47.6	10.3
2	.00	.00	6.4	1489	3.81	2.53	.077	.79	.23	.14	.00	.00	155	35.6	6.2
3	.00	.16	5.8	1480	3.94	2.36	.069	.82	.23	.07	.00	.00	153	34.9	6.2
4	.00	.00	6.4	1453	4.01	2.23	.071	.72	.23	.06	.00	.00	140	32.6	5.7
5	.00	.00	6.4	1485	4.10	2.12	.073	.64	.23	.05	.00	.00	137	32.3	5.7
6	.00	.00	6.4	1454	3.99	2.00	.073	.55	.23	.05	.00	.00	147	33.0	6.2
7	.00	.00	6.4	1499	4.18	1.95	.072	.44	.23	.06	.00	.00	148	35.3	6.1
8	.00	.00	6.1	1487	4.19	1.78	.080	.36	.24	.06	.00	.00	158	36.5	6.4
9	.00	.00	6.4	1484	4.20	1.65	.087	.33	.24	.05	.00	.00	161	37.8	6.5
10	.00	.00	6.1	1450	4.16	1.53	.095	.30	.24	.04	.00	.00	172	39.1	7.7
11	.00	.00	6.1	1477	4.23	1.37	.104	.29	.24	.05	.01	.01	178	39.2	7.5
12	.00	.00	6.0	1477	4.34	1.25	.119	.24	.25	.06	.02	.01	184	36.7	7.1

*Weighted average all taps gives 2.68 Si, 0.88 Mn.

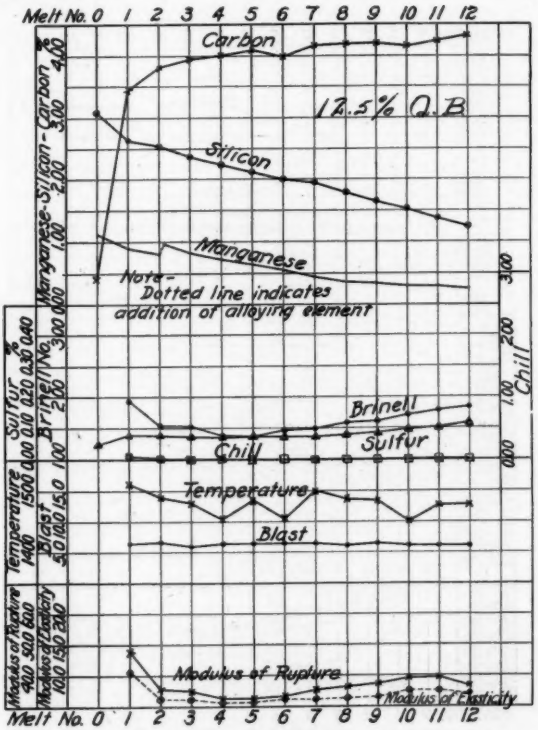

FIG. 10—EFFECT OF REPEATED MELTING. (SEE TABLE 10.)

Table 11

DATA ON REPEATED MELTS WITH CHARGES OF *A. B.* COKE (12½%) AND STEEL, USING 34-INCH BED AND 3% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill: Last white.	Chill: First gray.	Brinell.	Mod. of rupture.	Mod. of elasticity.
Orig.	2.90	.80	...	....	.40	3.08	.045	1.12	.20	.45	...	...	...	....	....
1	.00	.00	6.2	1519	2.45	2.26*	.099	.82*	.23	.05	.81	.43	269	63.0	17.4
2	.00	.00	5.9	N.R.	2.75	2.65	.111	.78	.28	.06	.14	.05	239	61.4	14.8
3	.00	.16	6.0	1461	2.92	2.40	.130	.74	.29	.04	.09	.02	219	58.3	12.9
4	.00	.00	6.3	1477	3.15	2.25	.132	.61	.30	.04	.09	.05	208	57.0	11.7
5	.00	.00	5.8	1495	3.24	2.20	.135	.47	.29	.03	.08	.05	209	55.2	12.0
6	.00	.00	5.8	1456	3.33	2.03	.135	.32	.30	...	.14	.07	217	50.1	13.2
7	.00	.00	5.5	1453	3.33	1.92	.153	.29	.29	...	.27	.25	246	51.7	13.8
8	.00	.16	5.2	1456	3.36	1.82	.165	.42	.32	...	.29	.18	226	55.5	13.6
9	.00	.16	5.2	1454	3.37	1.58	.177	.40	.32	...	.44	.30	230	58.8	13.8
10	.00	.00	5.2	1453	3.46	1.45	.167	.33	.31	...	.43	.38	239	55.7	13.6
11	.00	.00	5.2	1456	3.47	1.33	.185	.25	.32	...	.87	.75	276	39.1	14.4
12	.00	.32	5.5	1472	3.52	1.18	.184	.58	.36	...	.65	.43	217	57.0	11.6

*Weighted average all taps shows 2.68 Si, 0.86 Mn.

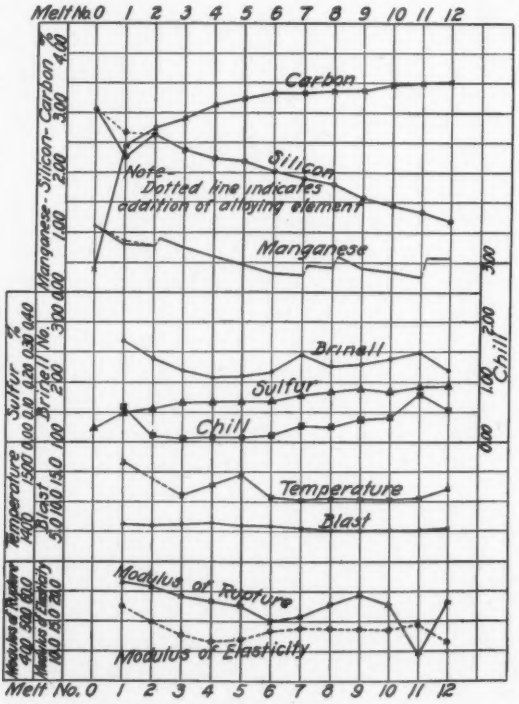

FIG. 11—EFFECT OF REPEATED MELTING. (SEE TABLE 11.)

Table 12

DATA ON REPEATED MELTS WITH CHARGES OF *R. B.* COKE (12½%) AND STEEL, USING 34-INCH BED AND 3% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill—Last white.	Chill—First gray.	Brinell.	Mod. of rupture.	Mod. of elasticity.
Orig.	2.90	.80	...	....	.40	3.08	.045	1.12	.20	.50	...	...	...	....	....
1	.00	.00	7.8	1498	2.02	2.82	.103	.90	.17	.10	.20	.06	263	55.8	18.4
2	.00	.00	7.5	1480	2.34	2.62	.137	.73	.18	.06	.11	.05	244	57.0	16.4
3	.00	.00	9.9	1480	2.60	2.47	.129	.60	.20	.04	.16	.11	239	63.1	15.0
4	.00	.00	9.3	1485	2.76	2.30	.161	.49	.20	.03	.28	.11	247	66.5	15.7
5	.00	.00	9.2	1474	2.79	2.17	.158	.40	.21	...	.35	.26	246	63.6	15.9
6	.00	.00	8.6	1495	2.81	2.05	.173	.30	.21	...	.72	.70	266	59.1	15.9
7	.00	.00	8.1	1456	2.76	1.80	.205	.28	.21	...	1.27	1.13	295	42.8	16.1
8	.00	.16	8.4	1472	2.84	1.64	.214	.43	.23	...	1.08	.83	254	58.8	15.3
9	.00	.16	9.3	1470	2.83	1.46	.232	.38	.24	...	2.17	1.50	279	43.5	18.2
10	.00	.16	9.0	1467	2.84	1.37	.248	.44	.25	...	3.00	3.00	372	47.2	21.1
11	.00	.16	9.3	1462	2.92	1.24	.252	.39	.29	...	3.00	3.00	351	46.1	22.0
12	.00	.16	8.7	1467	2.98	1.12	.241	.34	.31	.01	3.00	3.00	375	45.2	22.6

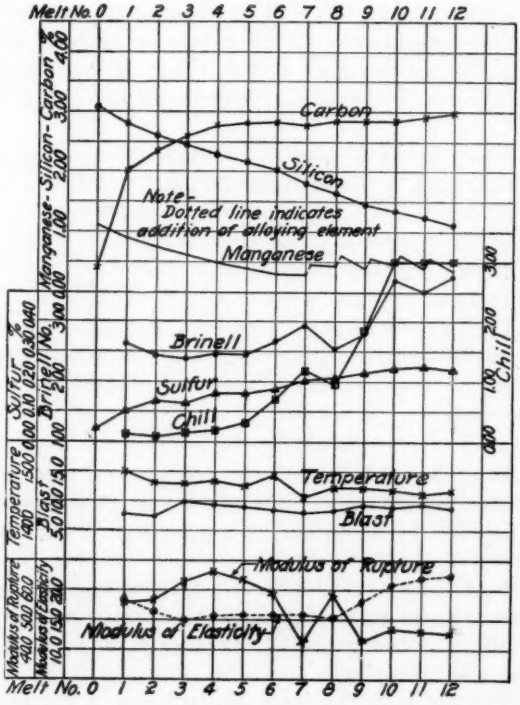

FIG. 12—EFFECT OF REPEATED MELTING. (SEE TABLE 12.)

small additions of manganese, which seemed to pull it back on heat No. 10 to 0.167. In heat No. 11, manganese was allowed to fall to 0.25, so the sulphur jumped back to 0.185; but a double dose of manganese in No. 12 gave 0.58 manganese and held the sulphur at 0.184.

61. There was only one ladle for a sample on this heat so we held it two minutes before pouring another set of bars, which gave only 0.143 sulphur and 0.48 manganese, showing how rapid the change is with excess manganese and plenty of carbon.

TESTS USING 12½% COKE, 8-11 OZ. BLAST AND 3% DOLOMITE

62. Tables 12 to 15 and the corresponding Figs. 12 to 15, inclusive, are the tests using 12½ per cent coke and a blast pressure of eight to eleven ounces with 3 per cent dolomite.

Coke R.B. and Steel

63. Table 12 and Fig. 12 show a steel melt with coke *R.B.*—a blast-furnace coke which gave exceptionally good temperatures. The carbon rose slowly, reaching 2.80 on the fifth heat and 2.98 on the twelfth. Silicon was allowed to drop on every heat.

64. Manganese was allowed to drop to 0.28 on heat No. 7; the sulphur, rising to 0.137, dropped to 0.129 on No. 3 and went rapidly to 0.205 in No. 7. Here small manganese additions were resumed, but they were not powerful enough to prevent a rise to 0.250, although virtual equilibrium appeared to have been reached—in fact, a slight drop occurred at No. 12.

65. The relation of chill to sulphur, manganese and silicon is quite remarkable, the carbon remaining conveniently constant. Nos. 11 and 12 would probably have chilled a larger test piece than three inches.

Coke W.B. and Steel

66. Table 13 and Fig. 13 show a test on steel and coke *W.B.*—another blast-furnace coke which also gave good temperatures. The silicon was caught up on the seventh melt and held for the rest of the test. Carbon rose to practically constant value at 3 per cent on melt No. 6. Sulphur slowly fought the manganese down in spite of continual additions and climbed to 0.208 on No. 9, although it fell back to 0.187 on No. 10, the manganese also dropping.

67. The last ladle was held two minutes, when another set of bars was poured. These showed 0.175 sulphur and 0.41

Table 13

DATA ON REPEATED MELTS WITH CHARGES OF *W. B.* COKE (12½%) AND STEEL, USING 34-INCH BED AND 3% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast Temp., pressure	Blast Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill—Last white.	Chill—First gray.	Brinell.	Mod. of rupture.	Mod. of elasticity.
Orig.	2.90	.80	...	....	.40	3.08	.045	1.12	.20	.50	...	...	...	....	....
1	.00	.00	10.8	1490	1.89	2.34	.119	.83	.24	.15	.63	.13	261	51.8	20.1
2	.00	.32	10.4	1460	2.36	2.12	.153	.85	.24	.07	.25	.14	242	58.6	17.5
3	.00	.16	10.3	1477	2.56	2.00	.182	.76	.24	.05	.27	.14	238	62.3	16.4
4	.00	.24	10.3	1513	2.65	2.01	.185	.72	.24	.04	.51	.24	247	68.4	17.1
5	.00	.24	10.9	1487	2.87	1.80	.171	.76	.29	.03	.58	.36	237	64.9	16.7
6	.00	.16	10.3	1470	2.97	1.68	.176	.63	.30	...	.62	.41	239	61.8	16.4
7	.20	.16	10.4	1460	2.99	1.68	.190	.57	.30	.03	.55	.37	231	67.1	16.2
8	.20	.16	10.3	1480	3.01	1.79	.201	.54	.30	...	.46	.32	231	62.0	16.2
9	.20	.16	10.3	1467	2.95	1.94	.208	.51	.30	...	.46	.31	232	63.8	16.7
10	.20	.16	10.1	1456	2.96	1.79	.187	.42	.30	.03	.53	.43	247	51.5	16.7

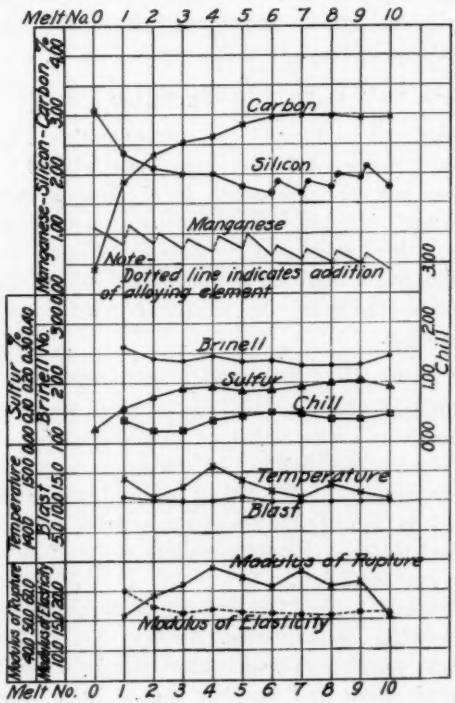

FIG. 13—EFFECT OF REPEATED MELTING. (SEE TABLE 13.)

manganese—scarcely any loss at all. The physical properties are remarkably uniform after the first melt.

R.B. Coke and Pig Iron

68. Table 14 and Fig. 14 show a pig-iron test with *R.B.* coke. Here silicon and manganese additions were begun on the second heat and continued through the test. The number of melts was insufficient to bring either carbon or sulphur to constant values.

W.B. Coke and Pig Iron

69. Table 15 and Fig. 15 show a pig-iron test with *W.B.* coke. The first five melts were made in very wet weather and the low temperatures are probably due to improper allowance for wet coke, etc. The carbon dropped to constant value on heat No. 8; sulphur rose to 0.15 on No. 6 and stayed there (with slight fluctuations) to No. 11, when it showed signs of rising further as the manganese slowly fell after staying practically constant for five heats.

TESTS USING 10% COKE, 8-11 OZ. BLAST AND 2% DOLOMITE

70. Tables 16 to 19 and the corresponding Figs. 16 to 19, inclusive, show tests on 10 per cent coke with 8 to 11 ounces blast and two per cent dolomite. In all four of these tests, the same silicon and manganese additions were made beginning with the second or third melt and continuing through the test. The relative amounts of these elements at the end of the tests thus furnished an estimate of the oxidizing conditions due to the difference in coke.

Pitch Coke, Steel and Ferrophosphorus

71. Table 16 and Fig. 16 show a steel melt to which 0.80 per cent phosphorus was added as 25 per cent ferrophosphorus. The pitch coke rapidly brings the carbon to saturation on melt No. 3 and the sulphur, after rising on the lower carbon to 0.072 on melt No. 4, is steadily beaten down to 0.056 by the manganese, which climbed to a practically constant value of 0.095 with only the 0.16 per cent addition.

72. As stated before, the variations in such carbons are due largely to pouring temperatures. In heat No. 12 the ladle from which the first set of bars was poured was held for five minutes, stirred several times and another set of bars poured. These showed only 3.45 per cent carbon, as against 3.79 per cent in the

Table 14

DATA ON REPEATED MELTS WITH CHARGES OF *R. B.* COKE (12½%) AND PULASKI PIG, USING 34-INCH BED AND 3% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill: Last white.	Chill: First gray.	Brinell.	Mod. of rupture.	Mod. of elasticity.
Orig.	00.	.00	...	....	3.91	1.50	.028	.81	.51	.12	...	...	...	....	....
1	.00	.00	8.8	1462	3.86	1.58	.052	.66	.54	.11	.00	.00	179	38.5	8.0
2	.15	.12	9.6	1480	3.70	1.72	.065	.70	.54	.08	.04	.02	172	36.8	9.0
3	.15	.12	9.3	1499	3.63	1.71	.070	.69	.56	.06	.08	.06	178	40.8	9.9
4	.15	.12	9.6	1467	3.54	1.75	.074	.68	.58	.05	.10	.05	181	44.2	10.3
5	.15	.12	9.3	1459	3.44	1.78	.080	.70	.58	.04	.10	.05	194	43.7	11.3
6	.15	.12	9.3	1472	3.36	1.78	.089	.63	.59	.04	.13	.07	202	46.2	11.9
7	.15	.12	9.3	1480	3.26	1.84	.098	.60	.58	.03	.11	.07	205	50.4	12.3
8	.15	.12	10.4	1448	3.17	1.87	.103	.57	.58	.03	.11	.08	220	54.2	14.1
9	.15	.12	10.7	1467	3.13	1.89	.122	.50	.58	.02	.13	.08	225	55.2	15.0

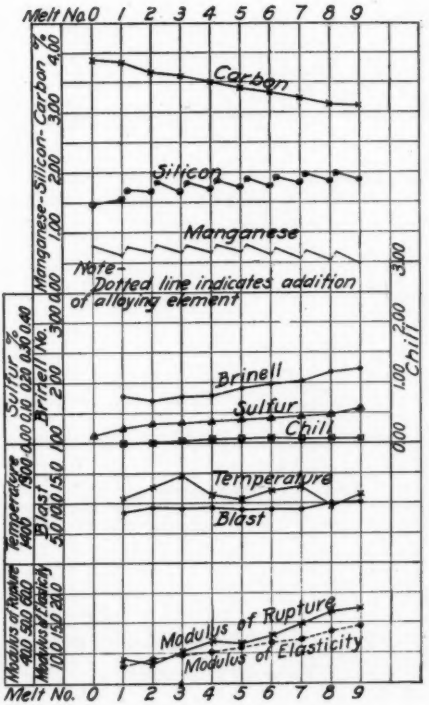

FIG. 14—EFFECT OF REPEATED MELTING. (SEE TABLE 14.)

Table 15

DATA ON REPEATED MELTS WITH CHARGES OF *W. B.* COKE (12½%) AND SLOSS PIG, USING 34-INCH BED AND 3% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	—Chill— Last white.	—Chill— First gray.	Brinell.	Mod. rupture.	Mod. elasticity.
Orig.	.00	.00	...	....	3.75	3.18	.013	.62	.76	.15	...	...	...	....	....
1	.00	.00	10.4	1463	3.41	3.08	.049	.55	.73	.11	.01	.00	173	38.8	9.2
2	.00	.00	10.7	1428	3.32	3.03	.073	.48	.75	...	.02'	.00	187	35.5	10.4
3	.00	.00	10.1	1397	3.20	2.79	.105	.40	.76	.07	.04	.01	199	41.0	11.4
4	.20	.16	10.4	1416	3.12	2.85	.120	.50	.77	...	.06	.03	209	47.0	12.8
5	.20	.16	11.0	1430	2.99	2.79	.144	.45	.77	.04	.06	.04	217	45.3	13.3
6	.20	.16	10.4	1442	3.00	2.87	.148	.53	.79	...	.05	.02	211	46.0	13.5
7	.20	.16	10.4	1439	2.96	2.89	.145	.54	.79	...	.04	.01	220	51.7	13.7
8	.20	.16	10.1	1439	2.87	2.75	.159	.53	.79	.02	.08	.04	220	50.1	14.7
9	.20	.16	10.7	1448	2.87	2.82	.145	.55	.80	...	.11	.05	225	47.6	15.5
10	.20	.16	10.4	1442	2.88	2.80	.152	.54	.78	...	.08	.04	231	52.9	15.7
11	.20	.16	10.4	1454	2.90	2.75	.160	.48	.80	...	.09	.04	230	53.5	15.5
12	.20	.16	10.3	1451	2.93	2.61	.154	.48	.81	...	.08	.05	231	56.7	15.3
13	.20	.16	10.4	1448	2.90	2.71	.163	.46	.83	.02	.08	.04	229	51.4	14.5

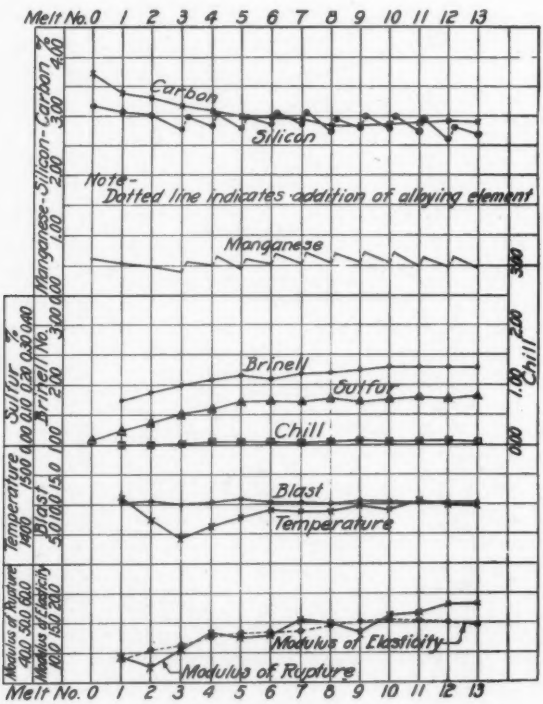

FIG. 15—EFFECT OF REPEATED MELTING. (SEE TABLE 15.)

Table 16

DATA ON REPEATED MELTS WITH CHARGES OF *Q. B.* PITCH COKE (10%), STEEL AND FERROPHOSPHORUS, USING 28-INCH BED AND 2% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill: Last white.	Chill: First gray.	Brinell.	Mod. rupture.	Mod. elasticity.
Orig.	2.90	.80	...	....	.40	3.00	.045	1.09	.90	.48	...	...	...	....	....
1	.00	.00	10.4	1472	2.89	2.28	.065	.73	.97	.17	.45	.19	242	53.3	15.5
2	.00	.00	10.4	1458	3.60	2.17	.067	.69	.95	.12	.02	.01	190	42.1	10.4
3	.20	.16	10.2	1456	3.66	2.23	.069	.74	.95	...	.00	.00	181	39.6	8.6
4	.20	.16	10.4	1459	3.71	2.31	.072	.77	.94	.08	.00	.00	170	37.6	8.3
5	.20	.16	10.1	1459	3.76	2.40	.064	.80	.93	...	.00	.00	164	34.3	8.2
6	.20	.16	10.3	1453	3.70	2.38	.061	.85	.93	...	.00	.00	165	34.0	8.4
7	.20	.16	10.1	1465	3.87	2.47	.067	.90	.93	.04	.00	.00	165	31.6	8.8
8	.20	.16	9.8	1465	3.69	2.42	.060	.88	.93	...	.00	.00	172	35.1	9.2
9	.20	.16	9.8	1453	3.80	2.43	.054	.92	.95	...	.00	.00	172	35.2	9.6
10	.20	.16	9.8	1459	3.69	2.55	.056	1.00	.94	...	.00	.00	181	36.7	9.2
11	.20	.16	9.8	1470	3.70	2.56	.058	.95	.94	...	.00	.00	175	33.1	9.0
12	.20	.16	9.6	1461	3.79	2.56	.056	.94	.94	.02	.00	.00	187	37.1	9.4

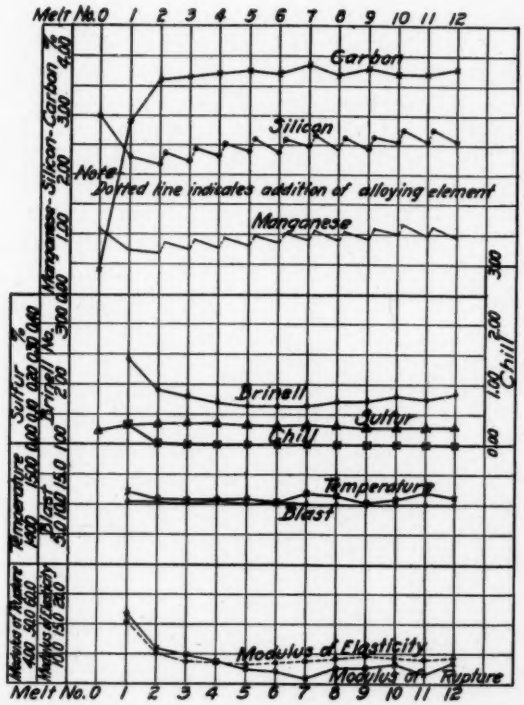

FIG. 16—EFFECT OF REPEATED MELTING. (SEE TABLE 16.)

first set—a loss of 0.34 per cent by weight of kish, of which there was over an inch to be skimmed off the ladle when the second set of bars was poured.

H.C. Coke, Steel and Ferrophosphorus

73. Table 17 and Fig. 17 show the same charge (steel, ferrosilicon, ferromanganese and ferrophosphorus) melted with the beehive foundry coke *H.C.* Except for the low result on No. 6, when the blower refused to function, the temperatures were fine. The blower also slipped badly on heat No. 8, but this did not begin until melting was well started and apparently did not affect the temperature.

74. The carbon climbed painfully to 2.70 (the first melt with 1.60 was lots of fun). The silicon settled at 2.30, as against 2.56 for the pitch coke; the sulphur stayed at 0.135 and the manganese at 0.60 until the last heat, when something seemed to happen. At this point the sulphur jumped to 0.167 and the manganese fell to 0.49 without causing any great change in the physical properties. The small amount of iron in this heat—480 pounds—may be the reason for the sudden break in the curve.

Coke A.B. and Normal Charcoal Pig

75. Table 18 and Fig. 18 show a test on a normal charcoal pig and the foundry coke *A.B.* which gave temperatures distinctly lower than the other cokes. No additions were made on the first heat, but the 0.20 silicon and 0.16 manganese were added from No. 2 on.

76. Carbon, although it slowed down after No. 6, continued to lose to the end. Silicon, starting from 1.16, gained till it reached 1.70, where it seemed to become constant. Sulphur rose steadily to heat No. 8, remaining constant through heat No. 11, and gained again as the temperature rose at the last. The physical properties were still slowly changing when the metal gave out on the fifteenth melt.

77. Louis Jordan of the Bureau of Standards determined oxygen and nitrogen by the vacuum fusion method on the first and fifteenth melts of this test. Oxygen rose from 0.005 per cent to 0.014 per cent and nitrogen dropped from 0.013 per cent to 0.007 per cent. The button from the oxygen determination on the fifteenth heat gave sulphur 0.006 and manganese 0.14. This was held thirty minutes in graphite under high vacuum at 1600

Table 17

DATA ON REPEATED MELTS WITH CHARGES OF *H. C.* COKE (10%), STEEL AND FERROPHOSPHORUS, USING 28-INCH BED AND 2% DOLOMITE FLUX

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill—Last white.	Chill—First gray.	Brinell.	Mod. of rupture.	Mod. of elasticity.
Orig.	2.80	.80	...	....	.40	2.90	.045	1.06	.90	.46	...	...	...	....	....
1	.00	.00	10.7	1506	1.61	2.59	.078	.68	.85	.20	1.56	.43	314	53.4	22.5
2	.20	.16	9.9	1452	2.08	2.64	.106	.68	.91	.09	.42	.24	271	50.9	18.3
3	.20	.16	5.2	1472	2.29	2.71	.120	.79	.87	...	.26	.11	274	55.2	18.4
4	.20	.16	9.9	1459	2.37	2.59	.123	.69	.90	...	.19	.11	259	52.8	18.7
5	.20	.16	9.9	1485	2.55	2.57	.142	.69	.91	.05	.23	.13	261	56.8	18.1
6	.20	.16	5.2	1416	2.55	2.59	.131	.69	.91	...	.11	.10	259	55.5	18.5
7	.20	.16	9.0	1467	2.62	2.52	.132	.65	.91	...	.20	.16	266	56.8	17.6
8	.20	.16	6.1	1477	2.74	2.43	.137	.57	.94	...	.26	.16	260	58.0	17.9
9	.20	.16	8.7	1462	2.70	2.31	.134	.58	.93	...	.20	.15	257	57.0	18.5
10	.20	.16	8.1	1467	2.66	2.32	.167	.49	.90	.03	.25	.20	264	54.9	18.1

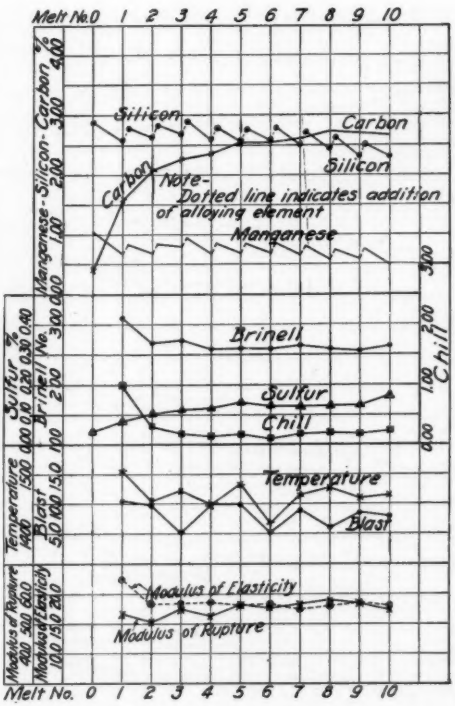

FIG. 17—EFFECT OF REPEATED MELTING. (SEE TABLE 17.)

Table 18

REPEATED MELTS, CHARGES *A. B.* COKE (10%), CHARCOAL PIG

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill—Last white.	Chill—First gray.	Brinell.	Mod. rupture.	Mod. elasticity.
Orig.	..	..	..	....	4.13	1.26	.011	.57	.51	.02	...	...	...	....	....
1	.00	.00	9.6	1400	4.01	1.16	.035	.48	.49	.02	.01	.00	153	34.7	7.8
2	.20	.16	9.9	1407	3.89	1.27	.052	.61	.50	...	.07	.03	162	36.2	9.2
3	.20	.16	10.0	1400	3.78	1.39	.067	.66	.50	...	.14	.06	174	41.3	9.3
4	.20	.16	9.9	1419	3.70	1.36	.084	.59	.50	.02	.17	.10	180	43.2	10.8
5	.20	.16	10.3	1394	3.64	1.41	.083	.68	.52	...	.21	.12	188	46.4	11.1
6	.20	.16	9.8	1419	3.58	1.49	.087	.63	.49	.01	.23	.15	201	48.0	11.9
7	.20	.16	9.8	1413	3.57	1.55	.094	.66	.47	...	.30	.16	212	52.8	12.6
8	.20	.16	9.3	1413	3.44	1.61	.103	.63	.49	...	.24	.15	212	54.2	12.8
9	.20	.16	9.0	1403	3.42	1.66	.101	.68	.50	...	.25	.15	215	52.2	13.2
10	.20	.16	9.6	1407	3.40	1.64	.101	.60	.49	...	.35	.23	221	55.8	14.3
11	.20	.16	9.8	1419	3.33	1.74	.099	.73	.52	.01	.20	.12	225	54.2	14.7
12	.20	.16	9.9	1442	3.34	1.64	.114	.58	.52	...	.40	.24	225	54.6	14.7
13	.20	.16	9.6	1428	3.27	1.74	.120	.64	.51	...	.26	.14	221	53.8	15.1
14	.20	.16	9.9	1430	3.24	1.70	.120	.57	.53	...	.29	.20	220	58.4	14.0
15	.20	.16	10.4	1410	3.20	1.70	.117	.52	.52	...	.30	.23	222	57.6	14.0

Melt No. 1—Oxy. 0.005; Nit. 0.013. Melt No. 15—Oxy. 0.014; Nit. 0.007.

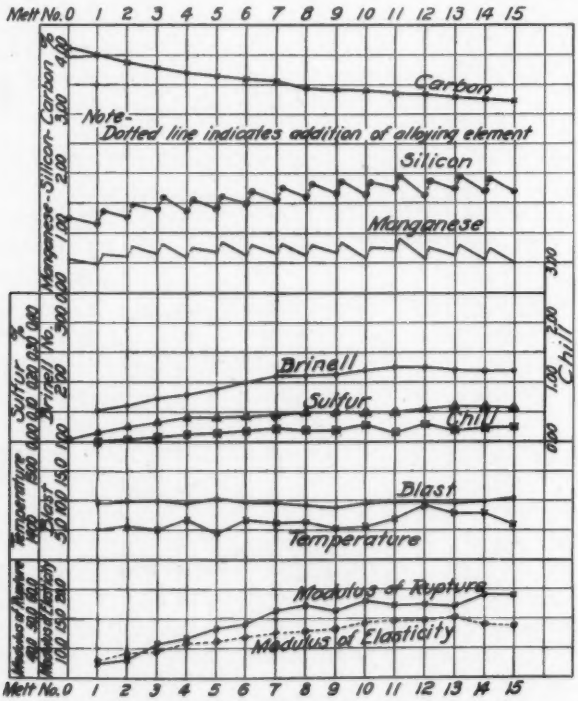

FIG. 18—EFFECT OF REPEATED MELTING. (SEE TABLE 18.)

Table 19

REPEATED MELTS, CHARGES *H. C.* COKE, CHARCOAL PIG, IRON SULPHIDE

Melt No.	Added Si	Added Mn	Blast pressure	Temp., degs. Cent.	C	Si	S	Mn	P	Ti	Chill—Last white.	Chill—First gray.	Brinell.	Mod. rupture.	Mod. elasticity.
Orig.	1.00	.00	...	....	4.01	2.26	.560	.57	.49	.02	...	...	...	....	....
1	.00	.00	8.6	1447	3.64	1.89	.267	.41	.48	...	.08	.08	210	37.8	10.3
2	.00	.00	9.4	1445	3.52	1.72	.221	.24	.48	...	.26	.25	227	41.9	12.1
3	.00	.16	8.6	1431	3.40	1.55	.231	.25	.49	...	.62	.52	243	41.4	14.0
4	.20	.16	9.2	1442	3.31	1.52	.222	.28	.50	...	.59	.49	245	43.4	14.2
5	.20	.16	9.3	1470	3.18	1.64	.239	.36	.49	...	.60	.54	255	49.9	14.6
6	.20	.16	8.7	1462	3.08	1.74	.219	.40	.50	...	.39	.37	254	53.4	15.4
7	.20	.16	8.3	1410	3.03	1.55	.199	.39	.51	...	.69	.63	258	51.3	15.4
8	.20	.16	8.7	1475	2.96	1.62	.236	.45	.50	...	.36	.32	238	57.9	15.4
9	.20	.16	9.0	1462	2.97	1.55	.232	.40	.51	...	1.03	.86	269	49.1	17.1
10	.20	.16	9.5	1492	2.97	1.56	.228	.47	.51	...	.74	.59	274	57.6	17.5
11	.20	.16	9.2	1477	3.02	1.54	.239	.43	.53	...	.81	.66	267	51.1	17.0
12	.20	.16	8.7	1453	2.94	1.52	.235	.38	.53	...	1.30	.92	297	38.7	18.4
13	.20	.16	8.7	1467	2.95	1.54	.220	.39	.54	...	1.55	1.14	330	37.2	19.6

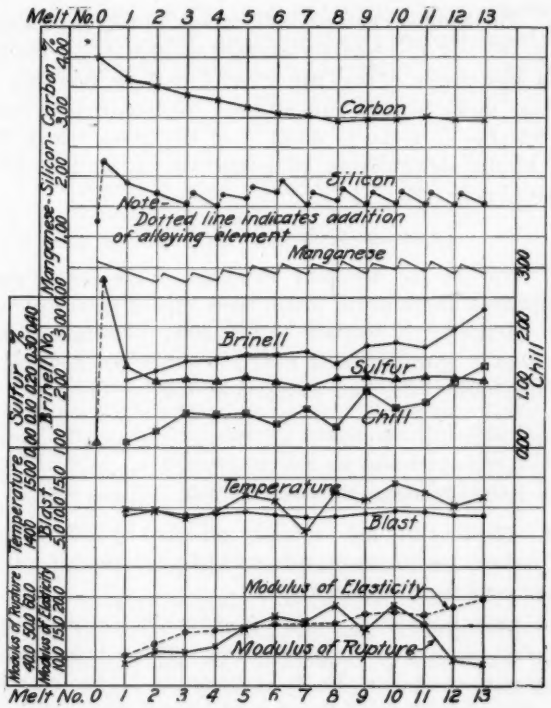

FIG. 19—EFFECT OF REPEATED MELTING. (SEE TABLE 19.)

degs. Cent., and probably comes fairly close to true equilibrium under the conditions.

Coke H.C. and Normal Charcoal-Pig Plus Sulphur Additions

78. Table 19 and Fig. 19 show the same charcoal pig, with the addition of fused iron sulphide sticks to give 0.55 per cent additional sulphur with the beehive coke *H.C.* Carbon reached a constant value of 2.96 on the eighth heat. Silicon, which was boosted to 1.89 on the first heat, fell slowly to 1.55, where it stopped.

79. After letting the manganese drop to 0.24 on the second heat, it was impossible to get it over 0.47 by the small additions made; thus it may be said to be constant at 0.40. Sulphur fell to 0.221 on the second heat and stayed practically constant throughout the test.

80. The sudden changes in hardness and chill on heats Nos. 9, 10, 11, 12 and 13 certainly are not explicable on the basis of the analyses given ("The Big Five"), and as they are all the same base material, the rare-element explanation is ruled out. There remains only the probability of the gases, which Mr. Jordan is kindly determining on heats Nos. 1, 11 and 13. (See discussion, page 432.)

Adjusting Carbons to Standard

81. Due to the different analyses of the tests—especially of phosphorus and silicon, which have such a powerful influence on the solubility of carbon—all carbon determinations were adjusted to a standard and nearly average analysis of silicon 2.00, phosphorus 0.50, and manganese 0.50, as follows:

1.00% silicon lowers carbon.....	0.21%
1.00% phosphorus lowers carbon.....	0.25%
1.00% manganese raises carbon.....	0.04%

82. These values are variously reported by different authorities, Fletcher, for instance, using 0.286 per cent for silicon and 0.387 per cent for phosphorus.

83. Certainly, if we correct first for silicon, then we cannot use the full correction for phosphorus. The values used assume that the pure compound Fe_2Si (containing 21 per cent silicon), and Fe_3P (containing 15.6 per cent phosphorus), will hold no carbon in solution, which is probably close to the truth at the

freezing point but not at high temperatures. Piwowarsky[17] shows experimental values of 0.24 for silicon and 0.35 (after correcting for 2 per cent silicon already assumed) for phosphorus at 1400 degs. Cent.

84. Since the corrections, as a rule, are small, not much error is introduced whichever rule is adopted. Table 20 shows that a larger correction for phosphorus would give more widely divergent values than those obtained.

85. These adjusted carbons are plotted for the several groups in Figs. 20, 21 and 22. In Fig. 21 the pitch coke stands far above the two foundry cokes. The *R.H.* tests converge at a point distinctly below the *A.B.* tests. A seven-melt test of pig iron and a five-melt test of a 25 per cent steel mix are plotted in this figure but are not given in the tables.

86. Fig. 21 shows only five tests with the two blast-furnace cokes, one of which—a five-melt test of pig iron—is not given in the tables. In neither case do the carbons converge, and the sulphur in both cases is higher on the lower-carbon metal than on the higher. Certainly the Fletcher correction of 0.018 (Mn — 1.8 S) is not nearly sufficient to account for the difference; but from the behavior of the high-sulphur pig in refusing to absorb carbon from pitch coke (Fig. 8, melt No. 1), there is evidently a powerful antipathy between sulphur and carbon which does not seem to have been worked out.

87. In Fig. 22 we have the two *H.C.* coke tests converging in spite of practically the same difference of sulphur, as occurred in Fig. 21. A test on pig with *A.B.* coke was planned for this group, but unfortunately time did not permit.

88. All of the melts on cokes *A.B.* and *Q.B.* are grouped in Fig. 23, which shows that no great differences in the carbon equilibrium point are found in a small cupola when small changes of blast or coke ratio are made. The principal difference in the position of equilibrium is in the character of the coke.

Relation Between Sulphur and Manganese

89. The natural relation to consider between sulphur and manganese is the product of the two, and this should be a function of the temperature. Figs. 24 *a, b, c, etc.,* show the most interesting tests plotted according to the order of melting. The

[17] E. Piwowarsky, *Hochwertiger Grauguss*, p. 43.

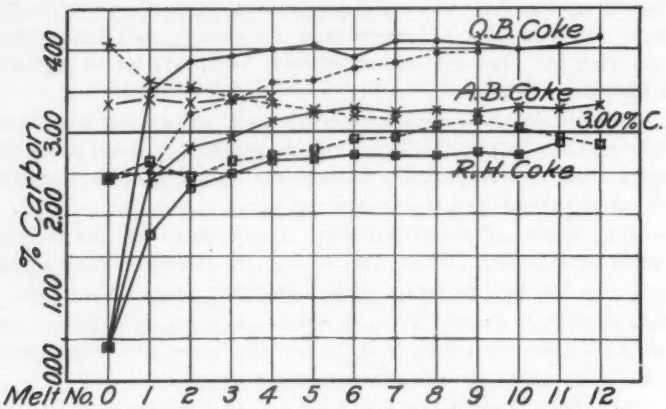

FIG. 20—CARBON ON ALL TESTS WITH 12½% COKE, 34-INCH BED, 3% DOLOMITE FLUX AND 6-OUNCE BLAST—CORRECTED FOR SI, P AND MN.

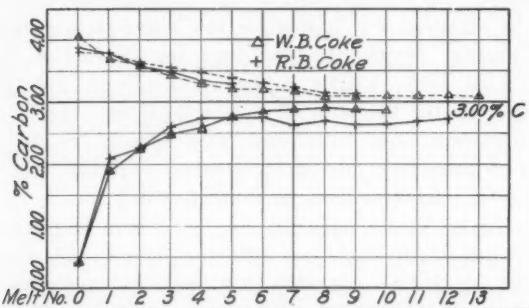

FIG. 21—CARBON ON ALL TESTS WITH 12½% COKE, 34-INCH BED, 3% DOLOMITE FLUX AND 9-OUNCE BLAST—CORRECTED FOR SI, P AND MN.

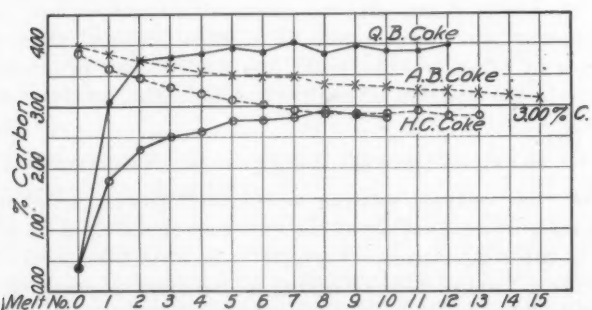

FIG. 22—CARBON ON ALL TESTS WITH 10% COKE, 28-INCH BED, 2% DOLOMITE FLUX AND 9-OUNCE BLAST—CORRECTED FOR SI, P AND MN.

temperature is marked by crosses and the manganese-sulphur product (per cent Mn $\times$ per cent S) is marked by circles, which are filled when ferromanganese is added to the cupola charge. Such addition, by maintaining an excess of manganese, keeps the product too high.

90. In a melt like Fig. 24 *c*, where the manganese addition was stopped after the third melt, the Mn $\times$ S product comes to a constant value in the eighth melt. In Fig. 24 *d*, where the manganese began very high, the product fell steadily to 0.045 after manganese additions ceased, jumped to 0.065 upon adding more manganese, fell back to 0.050 when manganese was stopped again, and jumped to 0.105 with an unusually heavy addition on the last heat. The effect of temperature is best shown in the

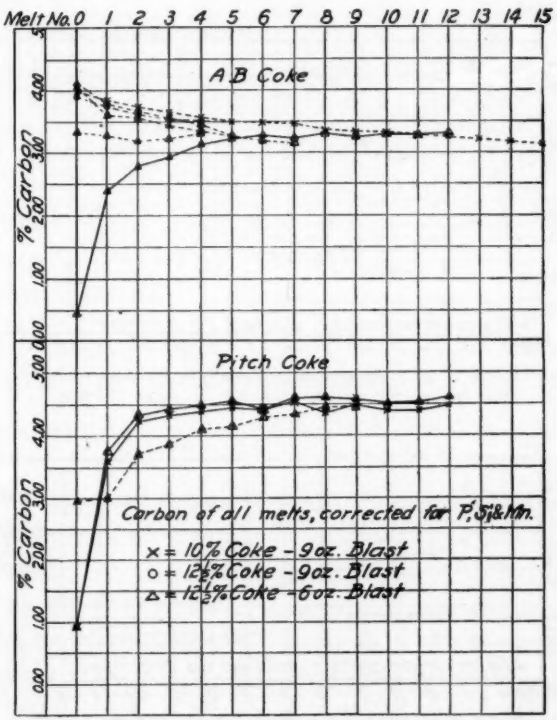
Melt No. 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
A B Coke
% Carbon
Pitch Coke
% Carbon
Carbon of all melts, corrected for P, Si & Mn.
× = 10% Coke - 9 oz. Blast
○ = 12½% Coke - 9 oz. Blast
△ = 12½% Coke - 6 oz. Blast

FIG. 23—CARBON OF ALL MELTS, CORRECTED FOR P, SI AND MN.

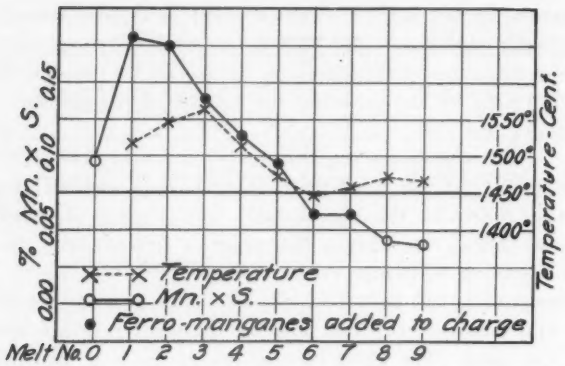

FIG. 24A—MN X S AS AFFECTED BY TEMPERATURE OF MELT (SEE TABLE 8). HIGH-SULPHUR PIG WITH 12½% *Q. B.* COKE (0.4% S).

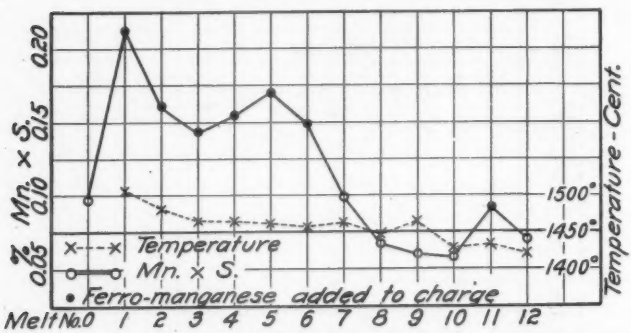

FIG. 24B—MN X S AS AFFECTED BY TEMPERATURE OF MELT (SEE TABLE 7). HIGH-SULPHUR PIG WITH 12½% *R. H.* COKE (1.0% S).

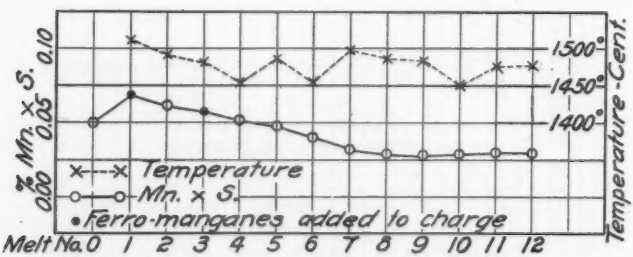

FIG. 24C—MN X S AS AFFECTED BY TEMPERATURE OF MELT (SEE TABLE 10). STEEL WITH 12½% *Q. B.* COKE (0.4% S).

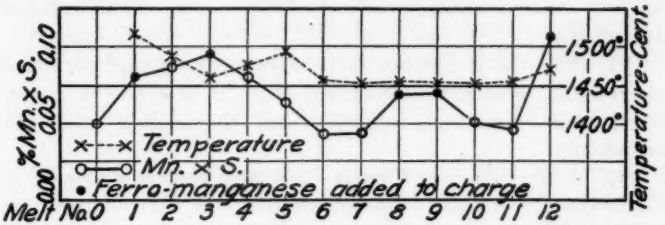

FIG. 24D—MN X S AS AFFECTED BY TEMPERATURE OF MELT (SEE TABLE 11). STEEL WITH 12½% *A. B.* COKE (0.6% S).

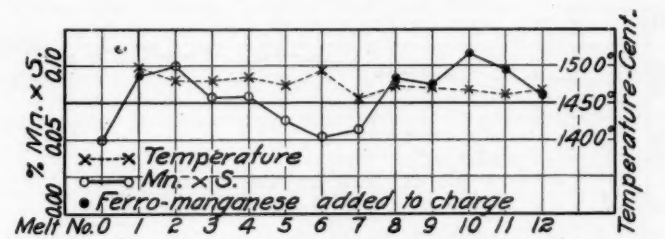

FIG. 24E—MN X S AS AFFECTED BY TEMPERATURE OF MELT (SEE TABLE 12). STEEL WITH 12½% *R. B.* COKE (0.9% S).

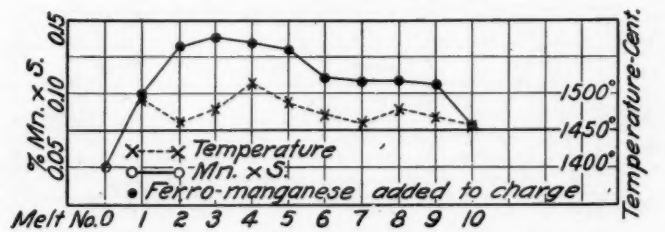

FIG. 24F—MN X S AS AFFECTED BY TEMPERATURE OF MELT (SEE TABLE 13). STEEL WITH 12½% *W. B.* COKE (1.0% S).

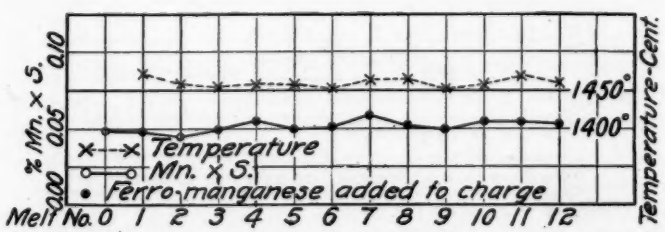

FIG 24G—MN X S AS AFFECTED BY TEMPERATURE OF MELT (SEE TABLE 16). STEEL WITH 10% *Q. B.* COKE (0.4% S).

last four figures, where the alloy additions were made uniformly throughout.

91. Fig. 24 *j*, for instance, shows remarkable correlation between the temperature and the Mn × S product. Fig. 24 *g* shows small variations in either, but they follow each other consistently.

92. Figs. 24 *h* and *k* have some inconsistencies but in general follow the others. The low spot in the temperature curve on Fig. 24 *k* was due to the fan slipping and did not knock the

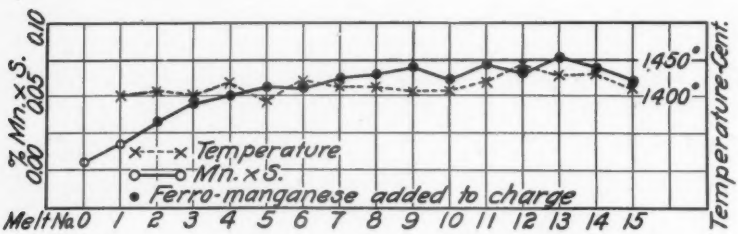

FIG. 24H—MN X S AS AFFECTED BY TEMPERATURE OF MELT (SEE TABLE 18). CHARCOAL PIG WITH 10% *A. B.* COKE (0.6% S).

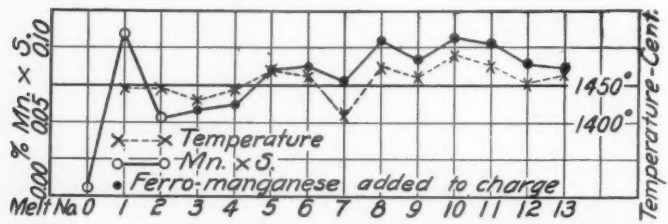

FIG. 24J—MN X S AS AFFECTED BY TEMPERATURE OF MELT (SEE TABLE 19). CHARCOAL PIG WITH 10% *H. C.* COKE (0.7% S).

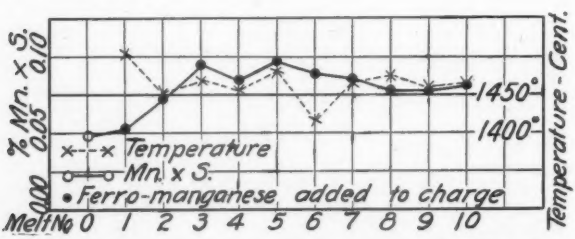

FIG. 24K—MN X S AS AFFECTED BY TEMPERATURE OF MELT (SEE TABLE 17). STEEL WITH 10% *H. C.* COKE (0.7% S).

Mn × S product much, although the low spot on Fig. 24 *j*—due to the same cause—did so. Probably the actual temperature of melting was not low in 24 *k*—the observed low temperature could be due to a delay in tapping out.

COKE DATA

93. In Table 20 are given the salient data on the cokes, including the ash, sulphur and burning-test results; the character of the original material, percentage of coke and approximate blast pressure; the temperature, carbon (corrected for silicon, manganese and phosphorus), phosphorus, manganese, sulphur and the product Mn × S, all averaged for the eighth,

Table 20

DATA ON COKES USED, AVERAGED FOR MELTS NOS. 8, 9 AND 10 OF EACH TEST MADE

Coke.	Orig. material.	Per cent used.	Blast pressure.	Ash.	S	Ignition temp., avg.	Min. for 250-deg. Fahr. rise.	Max. temp. rise.	Temp. of iron.	Corrected C in iron.	P	Mn	S	Mn×S
Q. B.	Steel	10	9	0.4	0.4	964	1.4	350	1459	3.91	.94	.93	.057	.053
	Steel	12.5	6	...	...	...	...	...	1474	4.05	.24	.33	.087	.029
	H. S.	12.5	6	...	...	...	...	...	1467	3.96	.87	.63	.065	.041
W. B.	Pig	12.5	9	9.6	1.0	992	2.4	269	1443	3.11	.79	.54	.152	.082
	Steel	12.5	9	...	...	...	...	...	1468	2.89	.30	.49	.199	.098
A. B.	Pig	10	9	10.0	0.6	1095	2.9	241	1408	3.35	.49	.64	.102	.065
	Steel	12.5	6	...	...	...	...	...	1454	3.27	.32	.38	.170	.064
H. C.	Steel	10	9	10.2	0.7	1005	2.6	259	1467	2.88	.92	.55	.142	.079
	Pig*	10	9	...	...	...	...	...	1476	2.87	.51	.44	.232	.102
R. H.	H. S.	12.5	6	13.6	1.0	N.D.	N.D.	N.D.	1448	3.12	.85	.41	.157	.063
	Steel	12.5	6	...	...	...	...	...	1470	2.73	.29	.46	.270	.124
R. B.	Pig	12.5	9	14.6	.9	1085	2.6	256	1467	3.13	.58	.50	.122	.061
	Steel	12.5	9	...	...	...	...	...	1470	2.67	.24	.42	.231	.096

*Ferrous sulphide added.
N.D.—Not determined.
H.S.—High-sulphur pig.

ninth, and tenth melts of each test—except where there were only nine melts, in which case No. 9 was used alone.

94. Fig. 25 shows the relation between the "time for 250-degree rise" in the Boegehold test, the carbon content and the temperatures. The minimum carbon and maximum temperature at 2.6 minutes is quite marked.

95. Fig. 26 shows both carbon and "time for 250-degree rise" plotted against the ash content. The carbon is due to fall with increasing ash content, but the burning characteristics of

the coke interfere powerfully. Possibly Bähr's work [18] on the influence of the impurities of the ash (notably, iron compounds) on the reactivity of the coke will some day furnish an explanation.

96. Fig. 27, in which the carbon is plotted against the temperature of the melt, is an interesting confirmation of Fig. 3 taken from Lorinser. It is quite consistent except for the pitch coke and the result would be preposterous if there were no

[18] H. Bähr, *Die Reaktionsfahigkeit (Verbrennlichkeit) von Koks.* Stahl u. Eisen, vol. 44, no. 1 (Jan., 1924), p. 1.

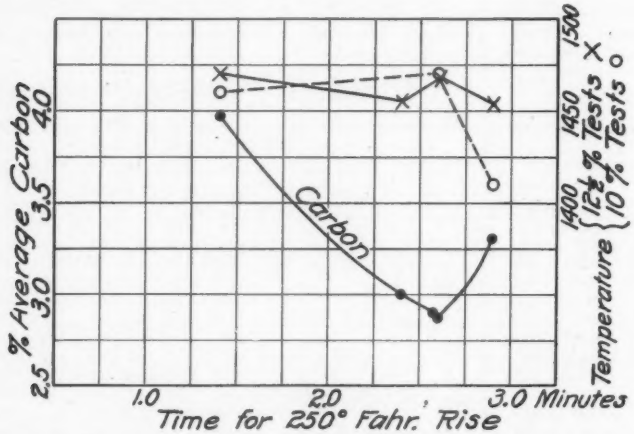

FIG. 25—RELATION BETWEEN BURNING TIME OF COKE AND AVERAGE CARBON AND TEMPERATURE OF THE 8TH, 9TH AND 10TH MELTS. THE 12½% AND 10% TESTS REFER TO THE AMOUNTS OF COKE USED IN THE MELTS.

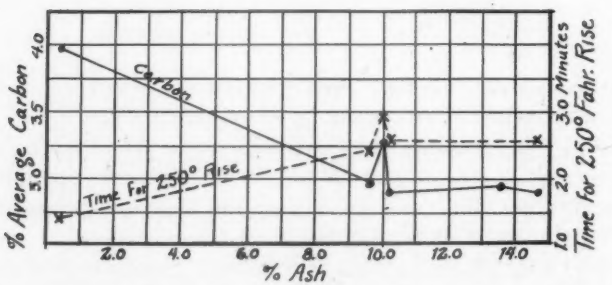

FIG. 26—RELATION OF ASH CONTENT TO BURNING TIME OF COKE AND AVERAGE CARBON OF THE 8TH, 9TH AND 10TH MELTS.

reversal as shown, for at some degree of purity coke must produce high carbon at high temperatures in spite of all other factors.

CURIOUS RELATION BETWEEN P. S. C. AND TEMPERATURE

97. A curious relationship—it may be only a coincidence—occurs between the phosphorus, sulphur, carbon and temperature in these tests. Table 21 shows the differences between the phosphorus, carbon, sulphur and temperature of the pairs of tests that are strictly comparable in all other factors; also, the difference in carbon content of the original raw material.

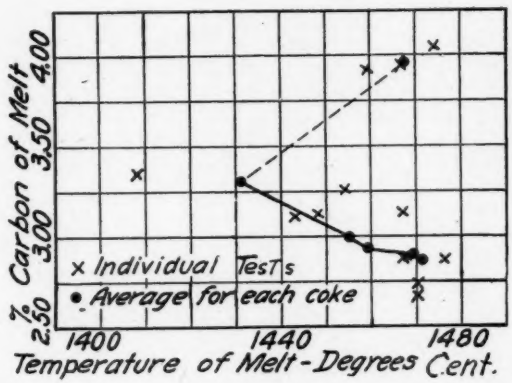

FIG. 27—RELATION BETWEEN TEMPERATURE AND CARBON ON THE 8TH, 9TH AND 10TH MELTS.

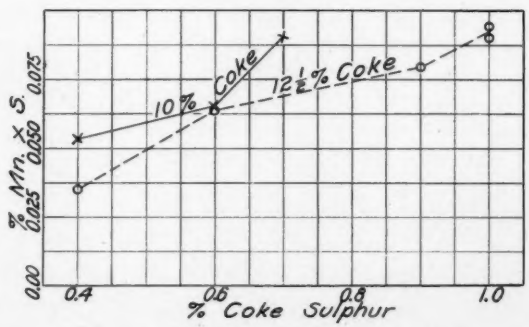

FIG. 28—RELATION BETWEEN SULPHUR OF COKE AND MN X S ON THE 8TH, 9TH AND 10TH MELTS.

98. Averaging the differences, we have the astounding result that one per cent phosphorus lowers the temperature 27 degs. Cent., the sulphur 0.140 per cent, and raises the carbon 0.41 per cent. Checking the slope of the line in Fig. 27 gives a change of about 0.35 per cent carbon with a 27-degree drop in temperature, which is not a bad check under the circumstances. It is well known that phosphorus lowers the melting point, but it is equally well known that it lowers the capacity to absorb carbon.

Table 21

RELATIONS BETWEEN CARBON, PHOSPHORUS, SULPHUR AND TEMPERATURE OF MELTS NOS. 8, 9 AND 10 (AFTER CORRECTING CARBON FOR SILICON, PHOSPHORUS AND MANGANESE), AND THE CARBON OF ORIGINAL MATERIAL

		Per Cent Excess			
	Orig. Material, carbon.	8th, 9th and 10th Melts			
Coke.		Carbon.	Phos.	Sulphur.	Temp.
Q. B.	+2.04	— .09	+ .63	— .022	— 7
W. B.	+3.67	+ .22	+ .49	— .047	—25
*H. C.**	—3.46	— .01	— .41	+ .090	+ 9
R. H.	+2.04	+ .39	+ .56	— .073	—22
R. B.	+3.40	+ .46	+ .34	— .109	— 3

*Sulphur added to the pig melt and ferrophosphorus to the steel melt.

99. Looking at the table more closely, we see that the high-phosphorus irons were originally high in carbon and the low carbons were from low-phosphorus material, except in the *H.C.* tests where phosphorus was added to the steel; but here sulphur was added to the pig iron. The logical conclusion is that the mutual repulsion of carbon and sulphur prevent the attainment of equilibrium under ordinary conditions, and that the phosphorus just happened to be on the same side in each test. The two pitch-coke tests show this, for the differences here are of the order and in the direction we should expect from the previous work on this system.

RELATION BETWEEN SULPHUR IN COKE AND IN IRON

100. The relation of the sulphur in the coke to that in the iron is shown in Fig. 28, where the Mn × S product is plotted against the coke sulphur. The point at 0.7 per cent is too high on account of the ferrous sulphide added to the pig on one of

the tests, and this never was given a sufficient excess of manganese to bring the sulphur down to normal for that coke.

101. The general relationship seems quite definite, and as we are using averages, the phosphorus and original carbons are very nearly the same for all points. The points for 10 per cent coke lie high on account of the constant manganese additions on this set of tests.

CONCLUSIONS

102. The conclusions to be drawn from the work are as follows:

103. Different cokes have a considerable influence on the carbon of the molten iron. In general, the ash content is a large factor; but differences of three or four per cent ash can be quite overshadowed by differences in the burning rate or other characteristics of the coke.

104. For ordinary cokes, the higher the temperature, the lower the carbon-equilibrium point. This probably is not true at either extreme of temperature, for pitch coke gives both high temperature and high carbon, while it is well known that a temperature low enough to cause oxidation gives low carbon. Whether this is due to oxidation during melting, or to reactions with the slag, is not known to the writer.

105. Some cokes did not give the same carbon, irrespective of the original carbon content for the number of melts tried. In other words, the tenth melt of a pig iron still had higher carbon than the tenth melt of a steel charge. Some cokes, however, gave the same carbon on the fifth melt of both pig iron and steel.

106. The "time for 250-degree rise" in the burning test was high on the coke giving the highest carbon (except for the pitch coke). It showed a minimum carbon at 2.6 minutes. There were not enough points on the curve to be sure of this.

107. Sulphur increases with the sulphur of the coke, *all* other things being equal.

108. Manganese has a strong influence on the sulphur, especially around a critical point which depends on the other constituents of the metal and on the sulphur and burning characteristics of the coke.

109. The manganese-sulphur product tends to remain constant with a given coke. It is raised by ferromanganese additions and increases with the temperature.

110. Carbon and sulphur are mutually repellant. A high sulphur iron is difficult to carburize and, on the other hand, a low-carbon iron absorbs sulphur readily.

111. A coke which gives low carbon gives a higher sulphur absorption than one of the same sulphur content which gives high carbon.

112. It is our duty to remark that there were a number of variables in these tests which are not entered in the log. The moisture and temperature of the blast, the skimming (or lack of it) of the iron, the size and shape of the pigs, the not-infrequent scaffolding of the small cupola, and the occasional boiling in the pig beds are a few of them which may have affected seriously some of the melts, and even a large part of a whole test. Any obvious occurrence was noted and none of them seems to affect the results; but it is well to realize that such things may have upset individual results here and there.

113. It should be noted carefully that this cupola is very small and the distribution of the tuyeres rather poor. Whether the latter has much effect is doubtful, but there is little doubt that the importance of different characteristics of coke and blast can change greatly with change in the size of the cupola. In fact they may easily reverse the direction of their action. Thus, while the shatter test does not seem to have any significance in the 18-in. cupola, there is no question about its value in the operation of a 72-in. cupola.

114. The burning test seems a promising method for the evaluation of coke. The three values reported from the tests varied so consistently with each other on these particular five cokes that it was only necessary to plot against one of them—the most convenient being the "time for 250-degree rise." Probably a determination of the reactivity of the coke with respect to carbon dioxide, which would furnish information as to the behavior of the coke above the melting zone, would give valuable information in conjunction with the burning test, although it is of very little value when used alone.

115. In conclusion, while we have no reluctance to draw conclusions from the tests, we sincerely trust that no errors of fact are made in the paper. Handling such a number of samples from shop to laboratory and back to shop again over a long period of time, weighing out high-grade alloys and breaking pig iron for a heat, can scarcely have been done to chemical precision.

However, we believe that no gross errors could have occurred.

116. As Darwin once wrote long ago, "false facts are highly injurious to the progress of science, for they often endure long; but false views, if supported by some evidence, do little harm, for everyone takes a salutary pleasure in proving their falseness: and when this is done, one path toward error is closed and the road to truth is often at the same time opened."

DISCUSSION

ORAL DISCUSSION

A. L. BOEGEHOLD:* In Tables 11 and 12 of Mr. MacKenzie's paper, it is interesting to note the difference in carbon pick-up of *A. B.* coke where 2.45 per cent carbon is obtained on the first melt compared with the *R. B.* coke called blast-furnace coke, where 2.02 per cent carbon pick-up is obtained on the first melt. I do not suppose that blast-furnace coke is more reactive than foundry coke.

Mr. MacKenzie, can you tell us anything about the properties of this blast-furnace coke that made it desirable for blast-furnace operations, in view of the fact that it seems to be less reactive?

J. T. MACKENZIE: Table 4 gives the data on these cokes. The coke *R. B.* shows a rather high temperature of ignition but gives a faster rise of temperature than the coke *A. B.* It also had about 14 per cent ash. The high sulphur probably had something to do with the reaction, as well.

E. E. MARBAKER:† What is the effect of the volatile matter in the different kinds of coke? Does the volatile matter simply go off?

J. T. MACKENZIE: I believe so. Unless it is reflected in the burning characteristics of the coke, we do not find any effect. In regard to the paper as a whole, I believe its principal significance lies in an appreciation of the different cokes, especially in the production of soft iron for one who wants easy machinability, or in the production of high-test cast irons.

If one wants to make a high-test cast iron with low carbon, then the thing to do is to find a coke that will give low carbon. Foundrymen know the cokes in their own districts (their coke supplies) better than I do, and I feel that the data in this paper should help them find a coke suitable for their particular needs.

As to the soft cokes, in gathering data for the British exchange paper[19] I used some combination of ordinary foundry coke and petroleum

*General Motors Research Laboratories, Detroit.
†Industrial Research & Engineering Co., Pittsburgh.

coke. A considerable section of the country has a large amount of scrap available, but coke is expensive and pig iron also is expensive. A foundry in such a district—by using a suitable proportion of even a hard pitch like some of the petroleum still residues, and a high-ash coke which may be available more cheaply than good foundry coke—can produce carbon of practically any degree desired from a scrap mixture.

The petroleum cokes, unfortunately, have a great deal of sulphur, so that it may be found advisable to desulphurize with some of the soda-ash compounds. On the other hand, the manganese-sulphide equilibrium shows that, if plenty of manganese is put in the iron, the sulphur tends to be much lower. Especially is this true with high temperatures.

In connection with these oxygen buttons which are taken to 1,650 degs. Cent. in a graphite crucible and held for one-half hour, in this paper I have described how the sulphur falls from 0.240 to 0.002, and the manganese from 0.50 to 0.05 in this treatment. This simply means that the manganese and sulphur are always trying to get out of the iron, if given an opportunity to do so.

Table 22

ANALYSES OF ORIGINAL AND RESIDUAL METALS

Melt No.	Sample				Residual Button	
	Oxygen.	Nitrogen.	Sulphur.	Manganese.	Sulphur.	Manganese.
1	.019	.003	.267	.41	.002	.04
11	.010	.008	.239	.43	.002	.04
13	.016	.009	.220	.39	.002	.04

I do not believe, of course, that this remelting to equilibrium is highly important, but in the foundry literature we find considerable regarding the much-dreaded building up of sulphur. This depends, of course, on the carbon content and on the silicon and manganese.

As a matter of fact, in ordinary practice, if 0.15 sulphur does not seriously affect the work, one could charge in 0.15 and tap out that same amount, so that one need not be afraid of the sulphur rise. Furthermore, the pick-up is very slow when high-sulphur material is charged. Unfortunately, the gas analyses do not explain the behavior of the melts of charcoal pig with coke *H. C.* (See Table 19 and paragraph 80.)

I am very much interested in the properties of coke, and this investigation was run largely with that idea in mind. I believe the coke man can take the results of this paper and use them profitably in their foundry work.

The results from the Bureau of Standards are shown in Table 22, with the sulphur and manganese of the remaining metal set against the original for comparison.

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[19] *The Properties of Coke Affecting Cupola Melting of Steel*, Jas. T. MacKenzie, Trans. Institute of British Foundrymen, vol. 20, pp. 46-56, 1927.

Induction Furnaces for Nonferrous and Iron Foundries

By Manuel Tama,* Finow-Mark, Germany

Abstract

Induction heating for electric furnace melting, first introduced in 1890, has resulted in development of three types of furnaces: (1) With open channels, (2) with submerged channels, and (3) with no melting channels proper but with a crucible-shaped melting chamber. The first type has been largely abandoned and recent developments have centered around the second and third types. The foremost problem in improvement of the submerged-channel-type furnace is said to have been the rapid transfer of heat in the narrow channels to the charge above. This phase is discussed in detail. With the third type, an important problem was the devising of methods of lining which could stand the high stress of alloys at elevated temperatures. Such linings have been developed and the furnace is now being used in some cases for melting or superheating iron as well as for melting nonferrous metals. Comparisons of iron analyses before and after treatment in the induction furnace are given.

1. Induction heating for electric melting furnaces became known in the field of metallurgy about 1890. The first patent relating to induction heating of which I am aware is the U. S. patent No. 428378, to E. A. Colby, issued May 20, 1890.

2. Various types of induction furnaces have been developed since then, which may be classified as follows:

(1) Induction furnaces with open channels,

(2) Induction furnaces with submerged channels,

(3) Induction furnaces having no melting channels proper, and a crucible-shaped cylindrical melting chamber.

3. Group (1) includes the following types of furnaces which are generally known by the names of their inventors:

*Hirsch, Kupfer and Messingwerke, Aktiengesellschaft.

Colby, Kjellin, Frick, Röchling-Rodenhauser, and other types which are not so well known.

4. These furnaces were used principally for melting iron and steel, with very little attempt at that time to melt non-ferrous[1] metals therein. Attempts were made but failed on account of the limitation of current density, due to the pinch effect about which Hering has reported in detail.[2] In view of the low power factor of these furnaces, it was necessary to adopt lower frequencies than normal for larger furnaces, and low-frequency alternators were required for frequencies down to 5 periods per second.

5. These and other drawbacks were the cause for this type of furnace, with a few exceptions, being abandoned. At present only groups (2) and (3) are important technically and economically.

6. It is a strange coincidence that the fundamental idea of the furnaces (2) and (3) was conceived in France, that both types originate from the same inventor and that they were fully developed by the same engineers in the United States, both technically and commercially.

7. The fundamental ideas of these groups (2) and (3) originated with the Schneider-Creusot Works, France, and have been described in French patents Nos. 339010 and 361627.

8. Two American companies, both under the executive direction of my good friend, G. H. Clamer, have been responsible for the technical development of these two furnaces. The author has been fortunate enough to co-operate in the development of these induction furnaces for Central Europe.

9. The author will now report on some new experience he has made with such furnaces, which are important for melting for casting purposes. First, however, I would mention the names of two investigators of furnaces with submerged channels, namely, the Americans Carl Hering and Edwin F. Northrup, whose work in connection with study of the pinch effect has been very important for the development of the furnaces.

10. In induction furnaces having submerged channels, the foremost problem was the rapid transfer of the heat in the narrow channels to the charge above them. Most of the patents

[1] Joh. Härden, *"Electrochemical and Metallurgical Industry,"* 1909, p. 478.

[2] Carl Hering, *The Working Limit in Electrical Furnaces Due to the "Pinch" Phenomenon.* Trans., Amer. Electrochem. Soc. (1909).

dating from about 1909 are concerned with this. Some inventors relied on mechanical means,[3] while others suggested the use of thermal movement.[4]

Pinch Effect

11. Carl Hering realized that at the transit from the melting channel into the hearth a suction action occurred due to the pinch effect by which intense and continuous motion of the molten charge is effected at the opening of the channel.[5] He compared this action of the pinch effect with that of a valveless electric pump.[6]

12. Reference is made to Fig. 1 for explaining this pumping action. Fig. 1*A* shows diagrammatically the opening of a melting channel into the hearth. The current flows through both and an electromagnetic field is formed around the conductor. This field has the tendency to compress the conductor, and this is what Hering and Northrup have styled the "pinch" effect.

13. The pressure distribution at the closely adjacent sections *x-x* and *y-y* in Fig. 1*A*, the areas of which are different, is shown in Figs. 1*B* and 1*C*. The hydrostatic pressure which increases from the surface of the metal downward is shown in Fig. 1*D*. At the point *x*, it is *Hx;* at the point *y*, it is *Hy*.

14. In addition, an inwardly directed pressure is generated by the pinch effect which, as can be shown by simple calculation, increases on a parabolic curve from the periphery of the channel toward its center, where the pressure attains its maximum. This pressure is

$$P = \frac{I^2}{\pi r^2}$$

Where *I* is the current, and *r* the radius of the conductor.

15. It is obvious that the pressure maximum *Py* in the smaller section *y-y* is smaller than *Px* in the larger section *x-x*. The closely adjacent points *a* and *b* are consequently subjected to various pressures and, as will appear from Fig. 1*C*, the pressure at *b* is higher than that at *a*, Fig. 1*B*. This causes the liquid conductor to be squirted out in the direction *b-a*, and the metal is obviously drawn back from the periphery of the channel.

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[3]German patent No. 271540.
[4]U. S. patent 761920.
[5]U. S. patent 988936.
[6]Trans., Amer. Electrochem. Soc., vol. 19, p. 255.

16. The action is similar to that of a propeller at *b* which permanently forces the metal up. This pumping action renders the operation of furnaces having submerged channels very reliable and prevents overheating of the channels, provided that the channels are properly dimensioned.

17. Hering considered the adaptation of his theory to electrode furnaces but failed on account of difficulties encountered with the electrodes. Clamer and Wyatt, however, realized that the Hering theory could be adapted to induction furnaces, and from their co-operation resulted a furnace (about 1917) in which Wyatt intensified the flow of the metal by the so-called motor effect in V-shaped channels.

18. The furnaces which were built on this system at first were used principally for melting copper-zinc alloys with a copper content up to 70 per cent. At present, such furnaces are successfully melting all copper alloys, also pure copper.

19. For the adaptation of these furnaces to sand casting, it was necessary to devise methods of lining which could stand the high stress of alloys of elevated melting points. The author

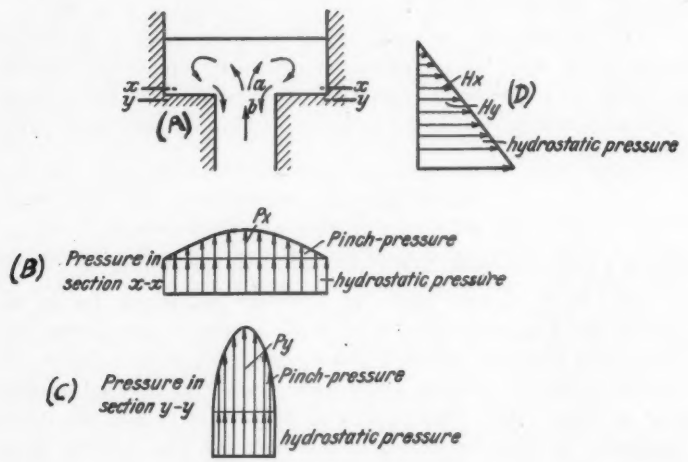

FIG. 1—DIAGRAMMATIC SCHEME ILLUSTRATING "PINCH" EFFECT. *(A)* OPENING OF MELTING CHANNEL INTO HEARTH. *(B)* PRESSURE DISTRIBUTION THROUGH CENTER VERTICAL SECTION OF *A*. *(C)* PRESSURE THROUGH SECTION *x-x* OF *A*. *(D)* PRESSURE THROUGH SECTION *y-y* OF *A*.

FIG. 2—AN INDUCTION FURNACE INSTALLATION IN A GERMAN FOUNDRY.

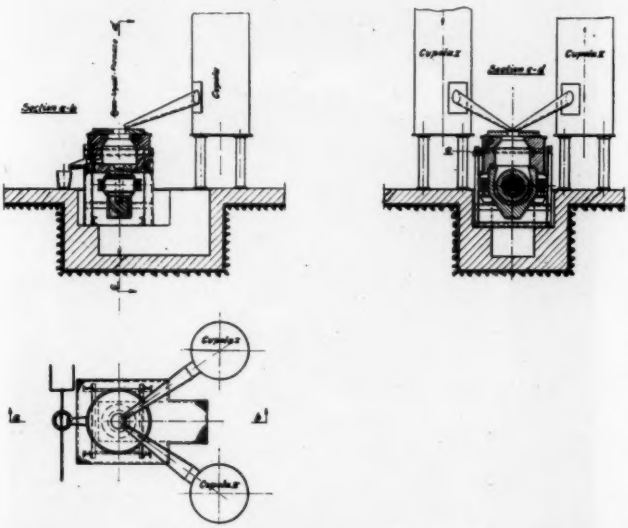

FIG. 3—DIAGRAM OF LAYOUT OF DUPLEXING PLANT FOR CAST IRON USING CUPOLAS AND AN INDUCTION FURNACE.

succeeded in building furnaces that were suitable for metal foundries and in which even cast iron could be melted. The linings of these furnaces were built on the method of Dr. Rohn, described in U. S. patent No. 1704902.

20. Fig. 2 shows a German induction furnace for casting fittings.

Application for Melting Cast Iron

21. The possibility of melting cast iron in the induction furnace opens new roads to iron foundries. The author has experimented for about 18 months and has now succeeded in superheating cupola-melted cast iron continuously in an induction furnace. The process is of the duplex type. (See Fig. 3.)

22. Runners extend to an induction furnace from two cupolas. The cast iron, which leaves the cupolas at 1400 degs. Cent. (2552 degs. Fahr.), is mixed thoroughly in the induction furnace, and superheated to 1580 to 1600 degs. Cent. (2876 to

FIG. 4—INDUCTION FURNACE USED FOR SUPERHEATING CAST IRON.

2912 degs. Fahr.). The induction furnace is stationary and is tapped as usual. Fig 4 shows the tapping hole.

23. The capacity of the furnace is 100 kw. and its output is 12 tons of cast iron per 8-hour shift. The power demand for superheating the cast iron for 200 degrees is 60 kw.-h. per ton, in continuous operation.

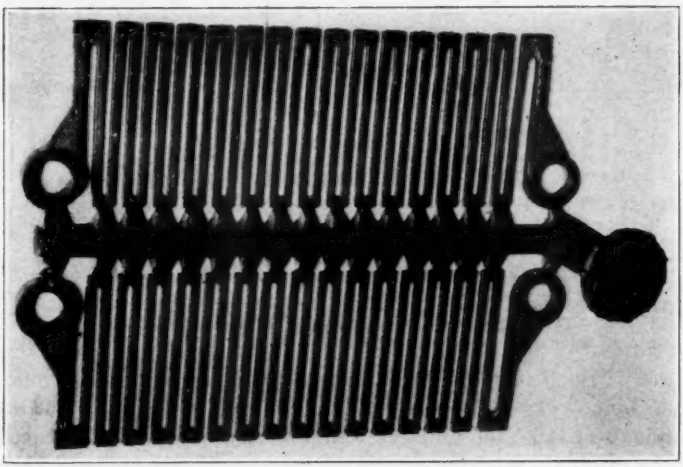

FIG. 5—THIN-WALL IRON RESISTANCE GRIDS CAST FROM INDUCTION-FURNACE-MELTED METAL.

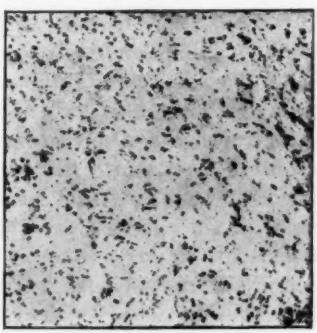

FIG. 6—MICROSTRUCTURE OF CAST IRON TREATED IN INDUCTION FURNACE. ORIGINAL MICROGRAPH AT 500X.

24. The furnace lining is made in accordance with Dr. Rohn's method, as follows: A templet of mild steel which has the exact shape of a channel is surrounded with dry powdered quarzite and the templet is heated until the quarzite is fritted. Further heating of the templet by induced current melts it down and the furnace is then ready for operation.

Table 1

Date.	Si	Mn	P	S	C	Combined.
IRON FROM OIL-FIRED FOREHEARTH						
7-31	3.07	0.54	1.02	0.106	3.26	0.10
8- 1	2.91	0.45	1.02	0.100	3.35	0.44
1-14	2.82	0.46	1.20	0.115	3.15	0.32
IRON FROM CUPOLA BEFORE ENTERING ELECTRIC FOREHEARTH						
1-21	3.13	0.64	0.76	0.105	3.20	0.30
1-23	2.54	0.64	0.80	0.103	3.27	0.28
1-24	2.38	0.63	0.76	0.105	3.16	0.49
IRON AFTER TREATMENT IN INDUCTION FOREHEARTH						
1-21	2.86	0.57	0.76	0.100	3.10	0.09
1-23	3.14	0.63	0.80	0.100	3.20	0.24
1-24	3.00	0.63	0.76	0.092	3.10	0.38

25. Such furnaces have repeatedly been operated for more than four weeks for the superheating of cast iron with the same lining, and it is not unlikely that the method can be improved so as to obtain still longer life of the lining. In January such a furnace was operated for four weeks in a foundry at Berlin, resistance coils as shown in Fig. 5 being cast from it. The cast iron from the furnace had the percentages of mixtures shown in Table 1.

26. The content of combined carbon, it will be noted, is less in the iron from the induction furnace.

27. Fig. 6 shows the structure of the induction furnace iron and the excellent distribution of its graphite.

28. The induction furnace is a most favorable superheater for cupolas. It not only will superheat the metal under economical conditions but also will mix it thoroughly. In oil-fired superheaters the metal is not agitated and the superheating is only superficial. Comparative tests have demonstrated that the action of the induction furnace is much more intense than in all existing superheaters.

(Discussion of the preceding paper is combined with discussion of the paper following, and begins on page 451.)

Study of Nonferrous Crucible Melting

By Harold E. White,* Pittsburgh

Abstract

This paper discusses the use of the nonferrous crucible melting furnace from various points of view—metallurgically, mechanically and economically. The efficiency of such furnaces are stated to be well over 10 per cent, as compared to 10 to 25 per cent efficiencies of other types which entail a large outlay for equipment. Control of factors affecting efficiency are discussed, some of the more important being: Design of combustion chamber, proper burners when using oil, and refractories. Decided advantages advanced for the crucible furnace include control of metal quality and low metal losses. Detailed comparative cost figures are given. A cost schedule outlining all cost factors which should be known when comparing costs is presented. The fields for future developments in crucible metal are said to be many and promising.

1. This paper is a study of the oldest, and one of the most reliable and economical methods of melting in use today. As it seems to be the order of things to attack our economic institutions on the basis of age, so has crucible melting often been maligned.

2. It is the one method of melting by which it is possible absolutely to prevent contamination of any sort, which consistently gives high quality, and which allows flexibility, both as to size of units and variety of alloys, without inter-mixture of any kind. Other types of melting claim similar advantages, but fail on the final analysis.

3. We will endeavor to show here the possibilities in this type of melting, and to outline modern practice, quality of metal obtained, losses experienced and accurate comparative cost data.

4. When considering crucible melting using solid, liquid or

*Vice-President, Lava Crucible Co. of Pittsburgh.

gaseous fuel, it must be remembered that the furnace itself becomes not only a melting chamber, but a complete chemical laboratory. The fuel is first gasified (in the case of coal, coke and oil) and then converted into heat. This heat must then be transferred by convection and conduction through the crucible wall to the metal. The problem is more complicated than it at first appears.

5. With electric melting the generation of electricity introduces several additional steps, especially where the electricity is generated from fuel. The efficiency is not so high as is at first imagined, and the economics of the situation are not apparent.

6. Solid fuel must first be converted to heat, this heat must be turned into steam, then into electricity and finally back into heat. One encounters boiler efficiency of 50 to 75 per cent, turbine efficiency of 75 to 80 per cent, electric generator efficiency from 88 to 95 per cent and transmission and transformer efficiency of 90 to 95 per cent. All of these considered bring the total conversion efficiency up to the time the electrical energy is delivered to 30 to 55 per cent and gives the net electrical furnace efficiency from solid fuel to molten metal between 10 and 25 per cent, in spite of the enormous outlay for equipment.

7. Efficiencies of oil- and gas-fired crucible furnaces of well over 10 per cent have already been recorded using furnaces now on the market. From a total efficiency standpoint, it is possible for the gaseous- or liquid-fuel-fired crucible furnace to surpass the electric furnace, as the latter starts with a handicap, while the former has only the flame efficiencies to deal with—and these are usually considered 90 per cent or better.

8. Some experiments have been made using powdered coal for crucible furnaces. This is an ideal fuel, as it is cheap and non-oxidizing. However, the units perfected at present are too large to be adapted efficiently to crucible furnaces.

FURNACE EFFICIENCY

9. Inefficiencies now present in crucible furnaces undoubtedly are numerous. The ease by which these furnaces may be improved is very apparent, and the difference between an inefficient installation and one of high efficiency is often a matter of only a few dollars.

10. The various items will be considered individually. In

hard-fuel pit furnaces, the usual combustion space for brass and bronze is three inches from pit wall to nearest part of crucible wall. However, for faster melting and higher temperatures this has been reduced to as low as 1½ inches.

11. Control of draft on both natural and forced draft hard fuel pit furnaces is essential. With some furnaces cold in the same battery and all using the same stack, the open draft holes on the cold furnaces act as a damper.

12. There are still a great many burners in use on oil and gas furnaces improvised from crude pipe fittings, but fortunately there are burners and other devices on the market which give correct mixing of gas and air and correct atomization of the oil. Local fuels and conditions must be taken into consideration.

13. Generally, it is best to supply air for gaseous fuel at the same pressure as the gas enters the burner, and to have sufficient capacity from the blower to give ten cubic feet of air for each cubic foot of gas required. Oil is best atomized at high pressure, using high-pressure air and supplying the secondary air needed for combustion at lower pressure.

14. Few oil- and gas-fired crucible furnaces have combustion chambers. The general theory has been to use the furnace itself as the combustion chamber. The result has been that most of the heating takes place in the upper third of the furnace, and the upper part of the crucible is cut down by the blast, while there is considerable life left in the remainder.

15. Some of our more advanced furnace manufacturers have recognized this fact and are providing combustion chambers so proportioned that the gases enter the furnace proper at its maximum temperature, at complete combustion, and literally wrap themselves around the crucible. The furnace walls also have been brought nearer to the crucible. This slight change has automatically increased crucible life and has decreased melting time.

16. The standard space between crucible wall and furnace wall is 1½ inches, plus or minus, depending upon crucible size and fuel used, even when heavy tongs require special grooves to be cut in the furnace wall. It is desirable, but not entirely necessary, to have the furnace wall follow the contour of the crucible.

17. The swirling of the gas or oil flame also has been given considerable attention. As many as three complete swirls have

been attained with a standard No. 70 crucible using gas fuel, by special design of furnace walls, whereas previously the average was as low as one-quarter swirl.

Silicon-Carbide Refractories for Furnace Linings

18. The use of silicon-carbide refractories in the furnace wall has been a decided improvement. Its physical characteristics make it a valuable material for crucible-furnace linings. It has the combination of high thermal conductivity, low specific heat, high diffusivity and relatively high heat capacity and low bulk density. It therefore heats up rapidly, stores a larger quantity of heat than most other refractories and gives it off rapidly when necessary.

19. Data of Table 1, secured from the *Transactions* of the American Ceramic Society, will give some idea of these figures by comparison.

Table 1

THERMAL PROPERTIES OF REFRACTORIES

Material.	Conductivity, gm.-cal. per sec. units.	Apparent density.	Specific heat.	Heat capacity per unit vol. per deg. temp. diff.	Diffusivity.
Fire brick	0.0034	1.905	0.245	0.467	0.0074
Silica	0.0040	1.56	0.265	0.413	0.0097
Magnesite	0.0095	2.60	0.273	0.710	0.0134
Crystalline alumina.....	0.0065	2.45	0.250	0.612	0.0106
Silicon-carbide	0.0258	2.45	0.228	0.559	0.0466

METAL QUALITY

20. There can be little question concerning the quality of crucible metal, for which there are several reasons. The metal is literally and actually wrapped up by the crucible and may be kept away from all outside influences by use of a crucible cover or charcoal and flux on the metal surface. It is difficult to overheat unintentionally, or to cause localized heating, such as may happen in arc-type furnaces to the metal directly under the arc.

21. The close range between melting point and boiling points of bronzes makes it necessary to maintain temperature control if good quality castings are to be secured, because at the boiling point the metal is liable to physical and chemical changes.

22. The melting points and boiling points of some bronzes are given in Table 2.

23. In order to maintain efficiencies it is essential not to overheat, and to pour when ready, as energy expended after metal reaches its pouring temperature is unnecessary waste.

24. There seems to be an opinion that nonferrous metals can be purified by trickling over incandescent carbon. This may be true were the carbon pure charcoal, but the reverse is apt to occur if applied commercially, as all such fuels contain sulphur and other volatile ingredients readily absorbed by metals.

Table 2

MELTING AND BOILING POINTS OF SOME BRONZES*

	Melting point, degs. Fahr.	Boiling point, degs. Fahr.	Pouring temp., degs. Fahr.
Copper	1981	4190	2250
Brass:			
90% Cu 10% Zn	1910	2730	2180
80% Cu 20% Zn	1830	2330	2100
70% Cu 30% Zn	1720	2090	1990
60% Cu 40% Zn	1620	1960	1890
Zinc	787	1700	....

*J. F. Quinn, *Gas Economics of Brass Melting.*

METAL LOSSES

25. In giving metal losses one is quite apt to compare experimental data such as determined on one installation as against averages which are, perhaps, of years' duration.

26. Volatilization losses should be determined at the furnace, and are directly chargeable to it. Spillage is an item independent of the melting equipment. It is mainly chargeable to the personnel, but partially to the pouring and carrying equipment.

27. Skimming may be due in part to the melting equipment, but may also be dependent upon the nature of handling equipment, type of work made, arrangement of casting floor and training of personnel.

28. The question frequently arises: Should the losses be computed on the basis of zinc or alloy? Undoubtedly the largest portion is zinc, although in all figures in this paper the entire loss is considered alloy. Were it all to be calculated as zinc, losses would be of much lower monetary value.

29. In order to secure a careful check on metal losses under

commercial operation, one of our large foundries was selected and a careful survey made extending over several weeks. The losses were determined as shown in Table 3.

30. Another set of figures from an entirely different source gives a total loss of 1.903 on red brass on a No. 70 gas-fired crucible furnace. One point which must not be lost sight of is the fact that metal losses naturally are lower when melting ingot metal than when melting scrap turnings or borings, and any comparable figures should be made on the same charge. General practice is to reclaim metal lost in skimming. This should be credited to the metal loss figure.

Table 3

METAL LOSSES

(No. 60 Oil-Fired Crucible Furnace)

Kind of brass.	Per cent of total.	Composition			
		Cu	Zn	Pb	Sn
Yellow	25	65	35	0	0
Red	75	80	4	6	10
		85	5	5	5
	Red brass	Yellow brass			
Volatilization loss	0.18	0.23			
Skimmings	1.13	3.91			
Spillage	0.60	0.70			
Total	1.91	4.86			

31. Actual volatilization losses from electric furnaces on normal operation have been recorded two to three times the above. It is normal to expect the same skimming and spillage loss. As a whole, then, true metal losses in modern crucible furnaces are lower than any other type of melting.

COSTS

32. It is worth remembering that any piece of equipment in a plant is only returning on the investment when it is in operation, and also that a large capacity furnace represents a loss as long as it is not melting metal to capacity. It is sometimes necessary to pour small heats; it is then when the large unit becomes expensive, and flexibility in the nature of several small units is at a premium.

33. When using crucibles it is possible to melt a different

alloy or metal each heat without the slightest possibility of contamination, simply by reserving a separate crucible for each metal used. What other form of melting allows this flexibility without enormous capital expenditures?

34. The cost data of Table 4 were secured from various sources: No. 5, from the Feb. 1, 1928, issue of *The Foundry;* No. 6, from *Transactions,* A. F. A., 1929; the other five sets are from industrial surveys made last year by a nationally prominent

Table 4

COST FIGURES

Cost per ton of metal melted	Type of Furnace: No. 60 crucible, oil-fired	No. 80 crucible, oil-fired	Vertical-ring induction	Oil-burning open-flame	Elec. horizontal arc rocking		
	1	2	3	4	5	6	7
Power and fuel cost...	4.13	1.62	6.39	15.48	8.25	8.35	6.03
Preheating cost.....			1.70		1.20	1.04	1.70
Crucibles and ladles...	1.35	1.35	1.75		1.25	0.29	1.75
Furnace maintenance..	0.62	0.45	0.59	2.30	2.60	2.76	3.11
Labor	2.28	1.99	4.06	7.70	2.38	2.30	3.30
Metal loss.....	0.58*†	6.78	3.00	12.00	7.60	5.76	1.44*
Total direct foundry costs	8.96	12.19	17.49	37.48	23.28	20.50	17.33
Fixed charges and overhead	0.35	0.17	1.51	0.78	2.18	2.18	0.98
Total cost, dollars per ton	9.31	12.36	19.00	38.26	25.46	22.68	18.31

*Volatilization losses only.
†0.59 for yellow brass.

PRACTICE FIGURES

	1	2	3	4	5	6	7
Power rate, cents per kw.-hour	....	....	2.13	....	2.68-3.20	2.59	2.00
Oil cost, cents per gal.	6½	4½	....	7½	8	8	....
Labor rate, cents per hr.	75	70	45-55	60	55-60	60	45-55
Metal melted.....	75% red, 25% yellow	Red brass	Yellow brass	Red brass	Red and yellow brass		Red brass
Plant production, tons per yr.....	2200	3300	1400	2000	1200	810	1200
Size of unit, lbs.....	185	250	1000	500	350	350	350
Volatilization loss at furnace, per cent.....	Red 0.18, Yellow 0.23	....	1	3	....	....	.5
Total metal loss....	Red 1.91, Yellow 4.86	2.75*	?	?	3	2.4	?
Kind of work.....	Brass fittings	Valves	Plumbing specialties	Automotive bushings	—Plumbing— supply work-general jobbing		Plumbing specialties

*Yearly figure without credits.

engineering concern in four large and very up-to-date foundries.

35. Note that in columns 3, 4 and 7 only volatilization losses are considered. If total losses had been available, the total figures would have been higher.

36. High-grade efficient crucible furnaces can now be supplied complete for from $300 to $500, a nominal capital investment, easy to move and which can be depreciated in a year's time without excessive burden on the total melting costs.

37. The publications of the foundry industry are replete with cost figures giving nonferrous melting figures from every conceivable angle. Quite a few of these are so compiled as to favor the particular type of melting under consideration. Still more forget entirely overhead and other fixed charges. A number do not take into account metal-loss figures, and if these are considered, often they are based on experimental data and not on total figures based on averages over long, normal operating periods.

38. For this reason the cost schedule, shown below, is submitted for comparing melting costs on an equitable basis:

COST SCHEDULE

Power and Fuel Cost.

39. This should include only fuel used in direct melting and incident thereto, such as slagging out, but may include fuel and power used to preheat crucibles and ladles and fuel used on crucible storage oven.

Preheating Cost.

40. Fuel used incident to preheating new linings or annealing new crucibles, and used on storage oven, of necessity belongs here.

Crucibles, Ladles.

41. Cost and maintenance of these items should include repairs to shanks and tongs.

Furnace Maintenance.

42. Cost of furnace linings, maintenance cements, maintenance and patching labor, repairs to shells, burners, electrode holders, tilting mechanism, etc.

Labor.

43. Here should be included only direct melting labor.

Metal Loss.

44. This item should be based, preferably, on cost of actual constituents lost from operation, using average figures from long periods of normal operation. These losses are usually high in zinc and other easily volatile constituents. Credits from the sale of skimmings and other such foundry scrap should be made here.

Total Direct Foundry Costs.

45. This item gives a total of factors directly chargeable to foundry personnel and equipment.

Fixed Charges and Overhead.

46. Interest on investment, depreciation, supervision, taxes. These items as a total are chargeable to the executive branch of the organization.

Total Cost Per Ton.

47. While the fixed charges and overhead item remains approximately the same for the same foundry, the total direct foundry costs will vary with different alloys, causing the total cost per ton to change.

DEVELOPMENTS

48. The fundamentals of nonferrous crucible melting are now the subject of intensive study in the industry. Some useful developments in furnace design have resulted already.

49. Actual determination of the physical characteristics of the various metal mixtures will have to be made with greater accuracy. Knowing, then, the melting points, specific heats and latent heat of fusion, and given the pouring temperature, we can calculate the sensible heat in the molten metal.

50. The thermal capacity of some of the types of furnaces now on the market are being investigated, as well as the heat losses of the same, along the following lines:

(1) By radiation while operating.
(2) Stack or exhaust losses.
(3) Pouring or discharging loss.

51. The temperature ranges of these types of furnaces—i. e., temperature at the base block and at intervals up to the top of

the furnace—are being determined as well as the velocity of gases and direction around the crucible, and the amount of actual heat recuperation contributed by so-called recuperative furnaces. Another point which is not lost sight of is the ease of working as viewed from the foundryman's standpoint. Lack of careful design on this point accounts for the failure or faulty operation of many furnaces.

52. The ideal furnace is one in which the crucible sets in a chamber of refractory material of high diffusivity, the chamber being so proportioned that it will not touch the crucible wall. The area of the combustion space must be carefully worked out so that it bears direct relation to the temperature to be attained and the volume of gases that have to pass through it.

53. The direction of the spent gases should be controlled, and they should leave the furnace at a minimum temperature. Recuperative heating should be taken advantage of, whether gas or oil is used.

54. The ability to charge the whole capacity of the crucible at one charge by means of a preheating hopper is an expected improvement. This will facilitate melting of fair quantities of borings and also will permit sealing off from the gases all the metal while it is being melted.

55. Air and gas regulators or diaphragms are an added improvement, as are also proportional mixers, since, unfortunately, pressures of air and gas vary for a number of reasons and those regulators assist in keeping the furnace working at top efficiency.

56. A feature of nonferrous melting is the difficulty of making adjustments in the presence of heat and fumes. The use of wedges and slots for assembling furnace parts which can be knocked apart with a hammer when repairs are necessary, are taking the place of tie rods, bolts and cap screws which must be chiseled off when they have to be taken apart.

CONCLUSION

57. It seems reasonable to expect—with the intensive research now being carried on both with crucibles themselves and with crucible furnaces and the inherent good features embodied in this type of equipment—that consumption of these com-

modities should be on the increase. This, in fact, is true; recent United States census reports show a reasonable increase in crucible products sold over the past few years.

58. It is interesting to note that the most outstanding development in metallurgical equipment, the Ajax Northrup induction furnace, has recognized the economics of crucible melting and has adopted crucibles as the metal container.

DISCUSSION

ORAL DISCUSSION

W. F. GRAHAM:* I understand that this furnace is operated continuously—that is, the forehearth is operated continuously for four weeks and, presumably, when they drop the bottom on the cupola the secondary ring freezes. Is that correct, Mr. Clamer?

G. H. CLAMER:† No, I imagine they maintain a liquid charge by keeping the power on.

W. F. GRAHAM: Was something said in the paper about burning out the ring when they rammed up the lining?

G. H. CLAMER: That is only to start it at the beginning of the campaign. That is the so-called Rohn Method. They do not use that every day, I do not believe.

W. F. GRAHAM: Then we have not gotten away from holdover yet? With respect to Mr. White's paper, I do not want to question Mr. White's sincerity in presenting the figures, and I agree with him heartily in his statements regarding the improvement in crucible practice.

It is unfortunate that we consider crucible furnaces simply as an oil barrel, as he said, lined up with some brick or rammed-in lining. However, it would seem that those figures should be questioned to a certain extent so that others might not be misled in their analysis of the data.

In the first place, I notice that 4½-cent oil is compared with electricity as high as 3.2 cents. It is questionable whether all fuel-oil systems can burn 4½-cent oil. I speak with some experience in that line.

Also, I question whether anyone would consider or should consider the installation of electric furnaces when the power company insists upon 3-cent electricity. Many power companies have come down in their rates when the matter has been presented to them in the proper light for heating loads.

I believe electric power is the one commodity in this country that is getting cheaper every year and more extensive in its application, due to the combined efforts of the power interests and the cooperation of

*Ohio Brass Co., Mansfield, Ohio.
†Ajax Metal Co., Philadelphia.

their power engineers with the possible consumers of their product.

The value of 2.68 to 3.20 cents, 2.59 and even 2 cents, is relatively expensive electricity if one is going to spend money for electric-furnace installation. I will not comment on the other figures, but just throw that out as a warning in taking these figures as a basis to make a decision regarding the relative merits of the furnaces.

I sincerely believe that crucible furnaces will never go into the discard. They are an absolutely necessary adjunct to foundry practice, in our experience. While the main portion of our tonnage is melted in electric furnaces equally of the two types (indirect arc and induction), we have an equal number of crucible-fired furnaces to take up the slack, for small heats and variable compositions of alloys.

One thing I did not understand was the value of eight cents given for fuel oil by Mr. White in Table 4, columns 5 and 6, which apparently refers to electric-furnace melting.

H. E. WHITE: That figure is for pre-heating ladles and things like that. Getting it in smaller quantities, they evidently have had to pay more. The amount is not very large.

W. F. GRAHAM: Then that is just the unit price that can be extended above into pre-heating cost.

H. E. WHITE: Mr. Clamer, in regard to Mr. Tama's paper, I notice the Rohn method is used in lining the furnace. Will you describe the method used in forming the block—if it was a pre-fired block, and what the refractory materials were? The author mentions quartzite. Is it pure quartzite, or is a binder used with it, and just how is the furnace lined?

G. H. CLAMER: The Rohn method consists in making an outline of the induction channel by sheet steel. That is, this part of the furnace is formed by what you might call a pipe—it is like a rain spout bent around and attached to this upper trough.

The quartzite is almost pure silica sand, probably with a little binder in it. The author does not give the exact description of that, and I am unfortunately not in a position to tell you if they do add a binder; I imagine they do.

It is not absolutely necessary, because, when the power is turned on, the sheet-steel form that is inserted is raised to a temperature sufficiently high to sinter the outside layers of the refractory and the material back of it will not allow the iron to get through because it is dry.

That is an important feature of the Rohn process. If it were dampened and tamped in, it would crack in drying; as it is put in dry, the metal is held.

Dr. Northrup also uses a somewhat similar method. He has a refractory cylinder that answers the same purpose as the Rohn metallic forms, and it is not necessary to melt out the form. Of course, this steel then becomes part of the first charge that is washed out very quickly. It is light and small in weight in comparison with the total weight of the charge.

H. E. WHITE: Is the cross-section of the channel in the bottom block in direct proportion to the conductivity of the metals?

G. H. CLAMER: Yes, that must be determined by calculation. There are very definite formulas for calculating channel dimensions.

CHAIRMAN E. F. CONE:* Mr. Clamer, have you any cost figures on duplexing of the cupola with this particular induction furnace? In this country it is not used that way. The ordinary arc furnace is used to make alloy irons and high-grade castings.

G. H. CLAMER: The only information I have is that given by Mr. Tama in his paper. That is, the power consumption is 60 kw.-hrs. per ton, and the lining cost, I imagine, is $200 for one month's operation, 25 days per month, 300 tons. Three hundred tons at $200 would be 66-2/3 cents a ton for the lining cost, and then there is the labor and all the other costs which must be added.

I should say that 1½ cents is considered about an average cost for power. That would be 90 cents a ton for power and about 60 cents a ton for the lining, making a cost of $1.50 a ton, plus the labor and distribution of overhead, etc.

A. H. CHAPPELKA:† Is the melting of metal by this process cheaper per ton, considering the use of a cheaper fuel, and is the lining cost and operation less? Is the cost of melting cheaper that way than it would be by melting directly in an electric furnace?

G. H. CLAMER: No, there is no intention of beating the cupola cost by using this method. It is merely a matter of the quality of the iron and of getting more fluid iron for running more intricate castings. The cost of the iron at the spout no doubt is greater than when melting in the cupola.

On the other hand, that may not be true if you take iron from the cupola at the same temperature. I do not know just how that would work out.

A. H. CHAPPELKA: Would it not be just as cheap to melt directly in an electric furnace—put the charge direct in the electric furnace at 1½ cents per kw.—as it would be to use the duplex method and get equally as good a product?

G. H. CLAMER: The cost of the actual melting probably would be greater, although there is always the possibility of cutting down the charge cost—that is, the raw material. For instance, borings and other scrap could be used which could not very well be put through the cupola.

There has been no real experience, so far as I know, and I have no reports on melting borings. I see no reason why cast-iron borings cannot be melted very cheaply and advantageously in this type of furnace. In the brass industry the furnace is very largely used for melting borings. In our own plant we have been using it for ten years for that purpose.

All the factors would have to be taken into consideration. The actual cost of the power as compared with the cost of coke, probably would be greater, but the ultimate cost of the fluid metal—the metal in the ladle—may be less.

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*Iron Age Publishing Co., New York.
†Lake City Malleable Co., Cleveland.

A. H. CHAPPELKA: By using a cheaper charge such as borings and scrap, which you use in your electric furnace, you still have your homogeneous mass in your furnace. Would it not be cheaper to melt directly in the electric furnace than to have this duplex process?

G. H. CLAMER: That is a possibility.

CHAIRMAN E. F. CONE: Would not the fact that one can melt low grade materials in the cupola and finish off faster be quite an item, Mr. Clamer? If a cold charge is put in the electric furnace, more current will be used. It is quicker melting and gives higher grade material, as I understand it.

G. H. CLAMER: It is a case of balancing the mixture cost against the cost of raising the iron to that certain high temperature. It may pay to use the furnace for melting cold charges because of the fact that the mixture cost would be less.

I may speak from rather a prejudiced standpoint in regard to the crucible, having been identified with the development of electric furnaces since 1912; but I fully realize that the crucible still has its field of usefulness. We use crucibles and fuel fires in our own plant.

We entered the field of developing electric furnaces as a means to an end, that end being to reduce our costs. Through that we got into the production of electric furnaces, the development of this type and the coreless induction type. Probably the best answer as to the field of usefulness and economy and efficiency of the electric as compared with the crucible is the fact that, in the wrought-brass industry, the crucible has been replaced to the extent of about 95 per cent.

I have seen the cost figures of the largest producers, and the electric furnace in its melting cost has cut the costs sufficiently to induce these large brass manufacturers to spend millions of dollars in the installation of electric furnaces. The mere cost of melting is only one of the factors, and although it is not by any means the smallest factor to be taken into consideration, it is the cost of the brass on the shipping platform that counts.

Through the installation of electric furnaces it has been possible to install scientific control of the product. Previously, the brass mills were throttled by the casters. They handled them with kid gloves, and one brass mill would steal a caster from another. They were the chief source of the labor difficulties in the brass mills.

All that has now been practically eliminated. The professional caster is not necessary. It is possible, with electric furnaces, to put on unskilled labor. A man can learn to operate an electric furnace in a very short time, and the reduction in cost all the way through the mill has been marked.

Probably the last thing that the big rolling mills would care to do would be to go back to their old method of crucible melting with all its labor troubles. That does not mean that the crucible is off the map, by any means. The crucible, for small production and in cases of intermittent work, probably will always be used, and particularly by the small foundryman who has not the money to put in an electric furnace.

An electric furnace, probably, will cost as much money as a lot of foundrymen have tied up in their whole business, and unless there is a sufficient output, the electric furnace should not be considered at all.

Notwithstanding the fact that electric refrigeration is here to the degree that we now have it for domestic purposes, I am told that the consumption of artificial ice is greater today than it has ever been before. That seems rather strange, but the answer is that, as a result of the advertising of the refrigerator manufacturers and the producers of ice, people who never did so before are now resorting to refrigeration in their homes.

Electric refrigeration has brought in a new consuming public. Many people having money to buy mechanical refrigerating equipment have put their old ice boxes on the second-hand market. These are bought up at a very low figure and immediately, as they are purchased, a new ice consumer is created.

I am told also that there are more candles used today than ever before. I do not mean per capita, but as a total. No doubt crucible consumption may be analogous. The crucible, too, has its place in industry.

As to the figures given in Mr. White's paper, I realize that cost figures are the most elusive of all figures gathered; and, unless the same language, in every respect, is spoken when you are talking about costs, they do not mean anything The one big factor is the quantity of metal melted in a given time.

Figures on electric furnaces, crucible furnaces or any other type of furnace may vary to the extent of 100 per cent or more, depending on the amount of metal that is obtained in a given time. That factor alone I do not believe the author has considered.

The figures I have seen—and which I know to be authentic, because large appropriations were based on them—rather reverse the figures given by Mr. White. That does not mean that that would follow in a small plant, by any means. The figures in a small plant might easily show that the crucible furnace could melt at half the cost of an electric furnace; but in a large plant with quantity production it is just the reverse of this.

H. E. WHITE: There is no improvement made in industry that does not affect another industry, and perhaps one of equal or greater importance. The crucible furnace today is not what it was three years ago.

This paper applies to the foundry industry and does not cover the rolling mills. I realize that the induction furnace is very popular in the rolling mill, but in the rolling mill the induction furnace has replaced the old-fashioned coke pit crucible furnace with its obvious disadvantages. I know of only one rolling mill that ever tried large-size tilting-type modern crucible furnaces. Of course, the old-time coke pit was very inefficient, but with it they were able to effect reasonable economies.

As far as crucibles being abandoned is concerned, I have only to refer to the last two census figures, which show an increase in crucible

production. Part of that increase is because the coreless induction furnace generally uses a crucible.

On the other hand, we have large installations of furnaces melting aluminum alloys which use crucibles. All of those account for this increase.

C. G. WICHUM:* Is there any advantage, other than superheating and thoroughly mixing the iron in this induction furnace, as to reduction in suphur due to more intimate contact with the slag? Is there any advantage in more thoroughly reducing the sulphur due to the flow or mixing action, the metal coming into more intimate contact with the slag?

G. H. CLAMER: That is a very advantageous application. At the present time forehearths are used that are unheated, the iron merely flowing below the desulphurizer. It is almost obvious that the sulphur cannot be reduced in that rapid manner as well as it can in the type of furnace where there is a circulation, as you state, bringing the iron up in contact with the desulphurizing slag.

CHAIRMAN E. F. CONE: Mr. White's reference to the Ajax-Northrup furnace, and the application of crucibles in it, rather shows that the two are going to be combined to some extent. Do you use a crucible in that furnace?

G. H. CLAMER: Yes, we use what might be called a crucible and there really is an actual crucible in the smaller furnaces; but when we get to the larger sizes, we have to put in a formed lining. Those furnaces are now being made in sizes up to 2½ tons, and one is even being designed for 3½ tons. In that case, of course, we have to abandon the crucible because of the size.

A crucible should be used where flexibility for changing mixtures is desired, and where there is not sufficient tonnage to support an electric furnace. We have electric furnaces and we have open-hearth furnaces in our own plant, and we also have crucibles (fuel-fired). They all have their definite field of usefulness.

We use the crucible where we want flexibility of operation, and where we are apt to strike a lean period and want to shut the furnace down and not have to pay a continual stand-by. That is one of the main factors. In times such as we have recently gone through—operating at only one-quarter capacity—when a crucible furnace is used it is like putting an automobile in a garage. It does not cost anything except garage hire while standing there; but a horse would be eating its head off while doing nothing. That is about the way it is between an electric furnace and the crucible furnace.

H. E. WHITE: You spoke of ramming in a lining for the electric furnace. We have been regularly supplying crucibles as large as 19 in. in diameter, in fair quantities. I know one concern that is now using a rammed-in lining, but other than that I am not familiar with this type of lining in the larger sizes in the coreless induction furnace.

Can you give us something on what type of lining it is and in

*Pennsylvania Radiator Co., Altoona, Pa.

what size furnace it is put? I did not know the Rohn method was being used in this country.

G. H. CLAMER: We do not exactly use the Rohn method. We use a cylinder of refractory, which is really a crucible except that it has a very thin wall section and it is merely used as a former to keep the dry, powdered refractory in place until the outside layers of the refractory are cintered so that the refractory as a whole will stay in place.

There are some places, no doubt, where the ordinary crucibles work out more satisfactorily even than that method. The Rohn method, as used abroad, simply is a shell of steel, if the furnace is used for melting steel, or it may be of nickel for melting cupro nickel. It is melted out, and in the melting operation sufficient heat is developed to cinter the lining.

H. E. WHITE: Is anyone using the Rohn method in this country?

G. H. CLAMER: No. We have not come to the use of it ourselves. We have the rights to use it, but as yet we believe our present practice is better.

G. S. DIAMOND:* Mr. Clamer remarked before that the brass-rolling mills have adopted to a very large extent the electric furnace for melting metal. So that any foundrymen here might not carry the impression that they had adopted that method to too great an extent, I want to say that they have been melting their straight copper in crucibles. As a matter of fact, they bought more crucibles in 1929 than they did in any other year in their history.

G. H. CLAMER: The reason that copper has not been melted up to the present time in the induction furnace has been due entirely to refractory difficulties—the copper oxide attacking the lining. However, there is some copper being melted in the induction furnace and I have the manuscript of a paper that was published in *Metal et Kunde* (Germany) in June, showing an induction furnace for melting cathode copper and pouring into vertical molds.

The authors contend that they are able to produce more cheaply better wire bars by that method than they now are able to produce even from the very large copper-refining furnaces. They have less scrap. That is a process that is being conducted now by the A. E. G., the big electric company in Germany.

H. E. WHITE: In replying to some of the points raised in this discussion, I wish to say that, on the cost figures as represented by Table 4, it was mentioned that 4½-cent oil did not favorably compare with electricity at 3.2 cents. The figures presented, with the exception of those in columns 5 and 6, were prepared with great care and at considerable expense. They represent a careful check of the records of the companies involved, so that there can be no question as to their source or authenticity. Columns 5 and 6 have been published as mentioned in the original paper.

Assuming that the cost is high and that 1.5 cents per kw.-hr. is the

*Electro Refractories Corp., Buffalo.

economical limit for power cost when melting nonferrous mixtures in the electric furnace, it is easy to make this adjustment in Table 4. A simple comparison would be to divide the power and fuel cost by two, which would give total cost items for columns 5, 6 and 7 of $21.34, $18.51 and $15.30, respectively. This would be on the basis of one cent for power for column 7, and a little less than 1.5 cents average for column 5.

Assuming a load of 400 kw.—which would represent a fairly large size unit of electric furnaces—for the Pittsburgh district, according to a representative of one of the large public utility corporations it would be difficult to obtain this power for less than 1¾ cents, as it costs ½ cent to generate it, to which must be added transmission charges.

One of the large railroad shops in this district using a large block of power pays one cent per kw.-hr. However, these are large installations, so that the figures in Table 4 are comparable and fair for the average foundry.

Every item possible has been included in these costs, including fixed charges and overhead, which have so frequently been left out when melting costs are considered. Power or energy costs, while a large item, can be made comparable on the basis of the fuel or power supply considered. However, depreciation charges determine whether an installation will be economical or not.

If it is necessary to have a large capital investment to use relatively cheap electrical energy, assuming that it is available, then the carrying charges on this large investment must be included and considered in any comparison of costs. There is a vast difference between the equipment necessary for efficient use of electrical energy to melt nonferrous alloys and that necessary for oil or gas for the same use.

It is hoped that this discussion will lead to the keeping of more accurate cost data and a better distribution of depreciation charges.

It is interesting to note that the largest installations of electric furnaces, principally in the wrought-brass industry, have replaced the old-type coke pits, and for this reason quite a saving has resulted. However, I question Mr. Clamer's figure of 95 per cent, in view of Mr. Diamond's remarks. It is reasonable to assume that, while the wrought-brass industry has reduced its costs, it is possible to effect a still further reduction with other methods, and I agree with Mr. Clamer that it is the cost of the brass on the shipping platform that counts.

Regarding the work of the professional caster, is it not a fact that the modern tilting-type crucible furnace can be operated with a lower class of labor than any of the present types of electric furnaces with their elaborate equipment maintained by high-priced electricians? We would very much regret to see the big rolling mills go back to their old methods of melting, but this does not preclude them from adopting modern methods of melting in tilting-type crucible furnaces using oil and gas for fuel.

Regarding speed of melting, the crucible furnace can be made a high-pressure production unit. Small pit furnaces now melt as high as 240 lbs. of copper in 30 minutes, and it is only necessary to refer to the capacities of the various plants, as shown in Table 4, which indicate the quantities of metal melted per year by the various methods.

This discussion has certainly brought out the flexibility inherent in the use of crucible melting furnaces.

One point does not seem clear, and that is the use of the plumbago crucible in large sizes in coreless induction furnaces. The fact that there is some induction in the crucible does not seem to be any serious drawback when the life and reliability of the crucible is considered. At the present time, in the United States and Canada, plumbago crucibles are used almost entirely for the lining of coreless induction furnaces when melting copper and nickel alloys.

Briquetting Cast-Iron Borings for Use in the Cupola

By Harry Rayner,* Detroit

Abstract

Earlier methods of briquetting and using briquetted cast-iron borings are discussed. After an investigation to determine the best equipment and possible savings, a machine was installed. The melting loss approximates that of cast-iron scrap. In regular practice, no difficulty is experienced using borings as high as 25 per cent of the total melt. At present a saving of about $2.00 per ton is effected. This saving will vary as the cost of scrap and borings varies.

1. Modern industry demands economical use of its waste material. Manufacturers machining cast iron consequently have had in mind methods of disposing of their borings. Various methods have been utilized for reclaiming this waste material, the market for which has been limited and the price therefore low.

Reclamation Methods

2. We will not burden you with the history or elaborate description of these methods, but will enumerate just a few so as to compare them with the most recent and what we believe to be the best methods. Some of the methods employed were:

1—Boxing in wooden containers.
2—Boxing in metal containers.
3—Melting loose in the reverberatory furnace.
4—Melting loose in the electric furnace.
5—Briquetting by use of a binder.
6—Briquetting by heating and compressing.

Why Old Methods Failed

3. The author has had experience with these methods and would not recommend any of them. Each has undesirable

*Foundry Metallurgist, Dodge Brothers Corp., Division of Chrysler Corporation.

features that condemns their use for the following reasons:

1—Boxing in wooden containers results in excessive loss and expensive preparation of the containers.

2—Boxing in metal containers. The containers are expensive but the loss is not so great as with wood. This method has been used quite extensively by a number of large concerns.

3—Melting loose in the reverberatory furnace results in excessive loss and heavy melting cost.

4—Melting loose in an electric furnace requires expensive equipment, and the behavior of the borings while melting causes a lot of trouble due to the material matting together.

5—Briquetting by use of a binder is practical but requires quite a lot of processing and resultant high handling cost.[1]

6—Briquetting by application of heat and compression[2] requires too much handling, which increases the cost.

Modern Briquetting Machine

4. The method used continuously by Dodge Bros.,[3, 4, 5] Detroit, since Oct. 12, 1926, has met with entire satisfaction and is the best method it has been our privilege to operate. By this method the loose borings are fed into a specially made machine compressed to a density of from 70 to 85 per cent without the use of any binder. Each briquette is 4 in. round by 3 to 5 in. thick and weighs from 7 to 10 lbs., depending upon the condition of the borings.

5. A description of the machine[6] and the experimental results derived from the use of the briquettes has been very thoroughly covered by previously published articles. As early as 1916 one author, writing[7] of his experiences in Germany, states that the strength, both tensile and transverse, is increased 40 per cent, that tendency to chill and shrink is increased and that loss varies according to percentage used.

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[1]J. A. Gardener, *The Foundry*, Feb. 15, 1924, pp. 153-156.

[2]J. A. Stillman, "Briquetting," Chemical Publishing Co.

[3]A. L. Prentiss, Description of Dodge Practice, *Iron Age*, Vol. 119, pp. 211-213.

[4]Description of Dodge Practice, Cassier's *Industrial Management*, Vol. 15, Aug., 1928, p. 265.

[5]W. L. Carver, *Automotive Industry*, Vol. 56, Jan. 22, 1928, pp. 80-81.

[6]G. Franke, "Handbook on Briquetting," Vol. 2.

[7]*Iron Age*, April 6, 1916, p. 842.

Predicts Standard Practice

6. Another, an American authority, referring to results of his experiments with this method, prophesied[8] in 1917 as follows: "Briquettes of cast iron have a very definite promising future in foundry practice. It seems conclusive that, used in moderation, they in no way injure the resulting melt and their use results in very great economy. It can be confidently predicted that briquettes, as a part of melting mixtures, will be standard practice."

7. Attention is called to these references in order to somewhat strengthen confidence in this method, created by having satisfactorily produced and consumed over 40,000 tons of these briquettes during the past three and one-half years—these references proving that this experience was not peculiar to any particular practice. Dodge Bros. pioneered the successful use of this method in continuous production in America.

Melting Loss

8. Some experiences in adopting this method are briefly summarized in the remainder of this article. Before purchasing a machine it was necessary to ascertain the melting loss incurred, and a series of tests were run to ascertain just what this would be in practice. A carload of cast-iron borings was shipped to a concern briquetting steel turnings in a similar machine to that required for cast iron. The briquettes were received in good condition and used for experiments which finally led to the purchase of a machine.

9. A small experimental cupola of 18-in. diameter was charged with 273 lbs. of briquettes. This charge was melted and pigged. The total pigged was found to weigh 259 lbs., giving a loss of 14 lbs., or 5.1 per cent. This loss is slightly higher than normal, due to the small heat in which small quantities of iron entrained in the slag or drop would give a higher computed loss. This would not be the case in big heats on a production cupola.

10. The results of this test show no abnormal loss in melting due to briquettes. Analyses of the mixture used and product obtained in this test were as shown in Table 1.

11. Heats containing briquettes were melted in large

[8] A. L. Stillman: TRANSACTIONS A. F. A., Vol. 25 (1917), pp. 493-502; *Iron Trade Review*, Vol. 61, Aug. 9, 1917, pp. 283-288.

cupolas and no difference found with the use of the briquettes than from regular practice, nor any difference observed in the properties of the resultant castings. The first tests were made with 10 per cent briquettes replacing the like amount of pig iron. No difference in the amount of loss was noticed with the use of briquettes in the mixture in this test or in subsequent uses of larger percentages.

Tests for Toughness

12. To ascertain what would happen to the compressed briquette upon heating to close to its melting point, a briquette was heated in an electric furnace to 2000 degs. Fahr. At red

Table 1

ANALYSES OF MIXTURE USED AND PRODUCT OBTAINED IN EXPERIMENTAL CUPOLA OF IRON WITH BRIQUETTE CHARGE

	Mixture.	Product.
	Analyses, per cent	
Silicon	2.42	2.18
Sulphur	0.092	0.112
Phosphorus	0.43	0.42
Manganese	0.56	0.48
Total carbon	3.47	3.12
	Physical Tests*	
Transverse strength, lbs.	2,600	3,800
Deflection, inches	0.105	0.140
Brinell hardness	178	228

*Taken from a test bar 1¼ in. round x 14 in. long, made in dry-sand mold; distance between supports, 12 in.

heat and up to 2000 degs. Fahr., the briquette was tougher and stood rougher handling than when cold.

13. It was thought that it might crumble due to releasing the strains set up by the compression during its forming. In the cupola partially melted briquettes were found still intact after passing into the melting zone, the cupola bottom having been dropped before the briquettes were totally melted.

14. Two 1-ton charges composed of 100 per cent briquettes were melted at the end of a regular heat and a product obtained satisfactory for soft gray-iron castings. This test was not typical of regular practice, however, because an extra large amount of

coke was used in order to obtain a "split" between the regular charges and the test. This created an excessively high melting zone in the cupola and accounts for obtaining softer iron than that produced in the experimental cupola mentioned above. The results obtained are shown in Table 2.

Table 2

ANALYSES OF BRIQUETTES USED AND PRODUCT OBTAINED FROM 100-PER CENT BRIQUETTE CHARGES MELTED AT END OF A REGULAR HEAT

	Briquettes.*	Product.
	Analyses, per cent	
Silicon	2.60	2.59
Sulphur	0.08	0.083
Phosphorus	0.18	0.19
Manganese	0.70	0.70
Total carbon	3.25	3.22
	Physical Properties	
Transverse strength, lbs.	3500	No. 1: 3,225 No. 2: 3,258
Deflection, inches	0.140	No. 1: 0.140 No. 2: 0.136
Brinell hardness	217	No. 1†: A: 187, B: 196 No. 2†: A: 187, B: 192
Tensile strength, lbs. per sq. in.		No. 1†: A: 28,000, B: 29,800 No. 2†: A: 28,250, B: 29,000

*These figures represent the regular run of castings from which the borings were taken, and are not the exact analyses of the briquettes used.

†A and B represent the two pieces created by transverse test, which were machined into test specimens for tensile test.

High Content Successful

15. In regular practice no difficulty is encountered in using percentages as high as 25. The following mixtures have been found entirely acceptable:

	Per Cent
Steel	20
Pig iron	35-55
Remelt (gates and sprues)	15-25
Briquettes	15-25

Melting Precautions

16. When melting mixtures high in scrap content, great care must be used in keeping the bed high in the cupola, otherwise the iron will be hard. The tendency to form cementite in the thin sections and corners will be greatly aggravated with a low bed and high percentage of remelt.

17. This condition cannot be attributed to the use of briquettes. We have proven that a like amount of scrap will give the same results under similar conditions.

18. During the year 1928, Dodge Bros. melted 3,161,517 briquettes or a total weight of 14,226.4 tons. Total running time of the machine was 4546 hours, producing 695 briquettes per hour, or 3.12 tons of borings briquetted per hour. As it was not policy to use purchased scrap, and as all the scrap gates and sprues were melted, this tonnage—14,226.4—represents the amount of pig iron replaced by borings.

Cost Data

19. Replacing pig iron at a market value of $18 per net ton, or automobile scrap at $19 per net ton, borings at $7.60 per net ton, plus $3.25 per net ton for cost of briquetting—this cost of briquetting includes every item connected with the operating of the briquetting machine, including overhead.

20. Replacing pig iron in the mixture with briquettes, we get the following:

	Per net ton
Cost of pig iron	$18.00
Cost of briquettes	10.85
Saving	$ 7.15

21. When replacing automobile cast scrap in the mixture with briquettes, we get:

	Per net ton
Cost of automobile cast scrap	$19.00
Cost of briquettes	10.85
Saving	$ 8.15

22. The above prices were computed from records of *Iron Trade Review* and *Iron Age* and represent average market prices

f. o. b. Detroit during the year 1928, and are not costs of the Dodge Brothers Corp.

23. The saving made by Dodge Brothers Corp., using market prices, is easily computed. It was their practice to replace pig iron with briquettes; therefore, the saving on 14,226.4 tons was $101,718.76 for 1928. Figures for 1927 show an even larger saving, but it is not the purpose of this paper to enlarge on any one practice but to show the economical and practical adaptation of the method.

General Considerations

24. Before contemplating the briquetting of borings, it would be advisable to consider a few facts that change the picture materially. First be sure that the mixture will absorb this additional scrap. Then there is the amount of borings, available to briquette, that will pay for the investment.

25. It also is advisable to make sure that the source of the borings is known. This is one factor that led to the successful use of the large tonnage mentioned above.

26. Recently, large consumers of automobile cast scrap have put briquetting machines into operation and have caused a large amount of automobile cast scrap to be dumped on the market. In their practice briquettes took the place of the cast scrap. Automobile cast scrap decreased in price from $19 per net ton in 1928 to the present price (on March 20, 1930) of $13 per net ton, making the saving at this time $2.15 per net ton instead of $8.15 in 1928.

Good Briquette Practice

27. Good practice will be to use automobile cast scrap as soon as the cost of briquettes equals that of scrap and this grade of scrap keeps below the price of pig iron. It will then be more economical to allow the briquetting machine to stand idle.

28. Those having taken advantage of the situation early can afford to do this as the machine has paid for itself many times. It would then act as a stabilizing medium for scrap prices controlling supply and demand.

DISCUSSION

ORAL DISCUSSION

R. S. MACPHERRAN:* What is the output per hour of the machine? What is the weight of each briquet? Does the cost given in paragraph 19 cover the depreciation of the machine? About how much is charged off each year for depreciation?

H. RAYNER: The cost given in paragraph 19 as $3.25 covers all charges. I tried to cover that when I said that the cost department put in all the charges they could imagine.

If we take this figure, the cost of briquets and the labor cost and what a $50,000 machine could be expected to cost in depreciation, it will be found that it is considerably lower than $3.25—it is approximately $2.12. Then put in the liquidation of the machine, which has to be taken care of in three years, and after that a depreciation of the machine which is almost the same amount. That is where the high cost comes in.

As to the size of the briquet, it weighs an average of eight pounds. During 1928 the number of briquets made per hour—taking into consideration all shut-downs and repairing the machine—was 695.

F. J. WALLS:† We do not agree with Mr. Rayner in his cost. Of course, he has had much more experience than we have had; he has been running four or five years, but we had only nine months' experience last year. Our actual cost last year was $1.91 a ton for briquetting cast-iron borings, which is considerably lower than his. Our cost included depreciation on the machine (10 per cent) and an installation cost of $67,000.

Our net saving during the nine months of last year in which we were operating was $61,000—mighty good returns on our investment. As to the quality of the castings obtained by using up to 20 per cent briquets in the mixture, and the quality of the metal itself, we have found no change either in quality of metal, percentage of good castings or machinability in our machine shop.

We have performed several tests running briquets one day and no briquets the next day or next two or three days, and we have followed these castings through. Our machine shop could not tell which day they used briquets and which day they did not.

In regard to Mr. Rayner's explanation of reducing action rather than oxidation as given in Table 2, he must have an exceptional condition there. I would not be able to get that in using straight pig iron, all polished up, and I do not see how anyone possibly could.

Many factors might enter into it. Perhaps they could not get an absolute analysis of the borings. Nevertheless, how one can put 2.60 silicon in and get 2.59 silicon out, I cannot understand. I should say that is very good cupola practice.

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*Allis-Chalmers Mfg. Co., Milwaukee.

†Wilson Foundry & Machine Co., Pontiac, Mich.

M. A. BLAKEY:* Mr. Rayner, why does Dodge not use all of their borings? Is it because of lack of capacity with their machine?

H. RAYNER: No, Dodge does not make all the castings which are put in the car. We found—by computing the weight of the casting delivered to the machine shop, taking that weight and subtracting the weight of the castings on the car, all cast iron—that it amounts to about 16 per cent. However, because we do not make all our own castings, we would have to absorb 16 per cent of all the castings we purchase—that is, all the castings that the Chrysler Corporation purchases, which would amount to nearly a thousand tons a day.

Our melt in the Dodge foundry is only 250 tons at present, so that we could not possibly absorb it.

CHAIRMAN H. W. GILLETT:** It looks as though, if you had the scale of operations so that you could utilize $60,000 or $70,000 worth of equipment, you could make a nice saving on it. What are we going to do with our borings when we are among the smaller fry?

I feel quite certain that Dr. Moldenke will have a word to say in comparing the briquetting method with his pet process of gluing them together with cement.

DR. R. MOLDENKE:† I do not like to say much about the process, because it is being superseded by another process in Germany as fast as the hydraulic presses wear out. However, I want to call attention to the fact that in TRANSACTIONS OF A. F. A., vol. 20, p. 489, there is a paper I wrote on the subject of briquetting cast-iron borings by the hydraulic pressure method.

Cement is not used for making briquets of cast-iron borings; it is used for cementing together ferroalloys into small briquets, to enable charging them into the cupola and melting without undue oxidation.

The present process used in Europe is to take the borings and put them in a large drum, fired through the lower end with a very rich gas to make them dull red hot without oxidation. As the hot borings get to the end of the drum, a batch is dropped through a slot in the drum into a suitable receptacle. This is run under a steam hammer, and in two blows the briquets are made, very much more cheaply than the old way. They have changed practically all their briquetting presses to this other method now.

H. RAYNER: Is that what is known as the Ronay process?

DR. R. MOLDENKE: The Ronay process is the original one of taking and pressing in a hydraulic press, as you do. It gave very good results. The only thing is that the material oxidizes too strongly in melting, and if one goes beyond five or ten per cent in the mixture, there is going to be trouble with hard castings.

If even the cleanest borings are analyzed for their iron content,

*International Harvester Co., Milwaukee.
**Battelle Memorial Institute, Columbus, Ohio.
†Watchung, N. J.

it will be found that never more than 85 per cent iron is obtained, so much dirt goes with them. Hence the idea of the German process of heating the borings to burn out all the oil, waste, etc., and thus get as clean iron as possible.

Did you ever make any melting test on the briquets direct, on a large scale, Mr. Rayner?

H. RAYNER: Only what I show on the end of the heat in Table 2, the table Mr. Walls criticized. I ran those two ton at the end of the heat after putting in the split of coke.

DR. R. MOLDENKE: That is a little uncertain. You may be fooling yourself a little on the melting loss. I made 50-ton heats of all briquets six days in succession and got the weights very accurately. I found we lost 20 per cent of the metal that was charged.

You really ought to run a very large heat of briquets, if only to get the melting losses; then you can figure on your regular heat just what your loss is.

Your cost is very high, also, for these briquets; but I see you explain it by the "overhead," which is perfectly proper.

H. RAYNER: The overhead there would probably make a difference in Mr. Walls' figure. Of course, we are absorbed by a large automobile manufacturing concern, and we take the overhead of the plant.

DR. R. MOLDENKE: What we are trying to drive at in any briqueting process is to get the specific gravity of the briquets up as near as we can to that of cast iron.

H. RAYNER: We find, when we get down to about 70 or 65 per cent density, that we do not get as good practice.

DR. R. MOLDENKE: They oxidize very badly in such an event. The carbon, silicon and manganese are reduced excessively, and the sulphur content is raised very much more than it would be in normal mixture melting.

GEO. W. MITSCH:* Mr. Rayner, will you give us a brief description of the machine you are using?

H. RAYNER: The machine is on the market and there are other machines also on the market. This was thoroughly covered in the references, both in regard to illustrations and particularly in Stillman's book. In Stillman's book he refers to Dr. Moldenke's paper on the different processes. In these references there is more information than I could give in two hours.

However, the machine is run by a 75-h.p. motor, through a series of gears in a sort of ram, and is cushioned by water; there is another safety cushion of air back of that. Between the ram and the press there is water, and when the briquet is being formed the ram gives a trifle.

In that way the entire effect of the briquetting—which is performed at about 50,000 lbs. per sq. in.—does not go back into the working parts

*American Car & Foundry Co., St. Louis.

of the machine. We have put on a higher speed motor and can turn out the borings much faster, but the machine eventually would be shaken to pieces.

A. E. RHOADS:* Mr. Rayner, have you poured permanent-mold castings from your metal?

H. RAYNER: I see no reason why you should have any trouble, any more than in using ordinary scrap, providing you take the necessary precautions with all scrap charges. You should have no more trouble than if you used all scrap.

A. E. RHOADS: My attention has been called recently to the case of a large manufacturer making permanent-mold castings as well as sand castings, whose experience has been that they have been unable to get sound permanent-mold castings. When they wish to pour permanent-mold castings, it is necessary to eliminate the briquets from the cupola burden. If they do not, the castings are full of gas holes—spongy from one end to the other. Eliminating the briquets, there is no difficulty and the castings are satisfactory.

If there is an adverse effect on the quality of the metal by the use of the briquets, this condition would be more likely to show up when making permanent-mold castings, but perhaps not sufficiently badly to show up when making sand castings.

H. P. KIMBER:** I happen to know what foundry Mr. Rhoads is speaking about, and something of their troubles. They are using some of our machines in connection with their sand foundry, and their principal difficulty lies in the type of briquet they are using. It is a small briquet about the size of an egg. Some of these briquets are very loosely pressed and fall apart. There seems to be something wrong with the way the borings are briqueted.

J. E. COON:† I believe both Mr. Rhoads and Mr. Kimber were speaking of Packard Motor. It is true that we have had difficulty in making permanent molds with mixtures containing borings. I disagree with Mr. Kimber that our borings fall apart. They are small borings, smaller than the Dodge borings, about two inches in diameter and about the same in height.

We do not have much difficulty with them falling apart, and we have had them come out of the drop still in a solid condition. We found that they gave considerable trouble in permanent molds and, consequently, we have discontinued them altogether.

R. S. MACPHERRAN: Mr. Coon, have you stopped using borings altogether in permanent molds, or altogether in foundling?

J. E. COON: We have abandoned them altogether in founding.

*Detroit Electric Furnace Co., Detroit.
**Holley Permanent Mold Machine, Inc., Detroit.
†Packard Motor Car Co., Detroit.

Notes on Behavior of Sand Molds in Steel Foundries

By Paul L. Goodale,* Granite City, Ill.

Abstract

The purpose of this paper is to call attention to the importance of the characteristics and properties of core surfaces when casting steel against them. The incandescent metal of the surface of the casting burns in contact with air, forming an oxide slag which, being very fluid at pouring temperatures of steel, penetrates readily in between the sand grains of an open core and forms some iron silicate by action with the sand. In dry-sand cores some of the oxide is reduced back to iron, forming a mass of magnetic material. The author advances various ideas which may be studied to overcome this objectionable feature of slag formation, which presents difficulties in obtaining smooth steel castings.

1. It is the purpose of this paper to draw attention to the importance of the surface oxide, when casting steel in sand molds. It is self-evident that the burning of liquid steel always occurs on its surface, whenever it is in contact with the atmosphere. Since the sand mold for a casting is permeable, atmospheric pressure suplies the requisite oxygen for combustion of some of the steel cast in it.

2. When molten steel is poured into a mold constructed so that a surface of the liquid metal is exposed to the air, certain phenomena always manifest themselves. The incandescent iron burns at the surface exposed to the air, combining chemically with the oxygen, forming a compound known as iron oxide.

3. Fig. 1 is a drawing of the cross-section of the upper part of a steel ingot. The oxides are designated as *A* and *B*. *A* is the first oxide formed. It has a different coefficient of expansion than that of the steel beneath, and therefore flakes off, again leaving

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the steel surface exposed to the air. The surface is now cooled to about cherry redness but is still hot enough to burn slightly to form oxide *B*, which adheres very tenaciously.

Analyses of Oxides

4. The oxide *A* was found to be a mixture of ferrous and ferric oxides, analyses of which gave results of which the following are typical:

Fe_2O_3, per cent	34.60
FeO, per cent	62.31
MnO, per cent	.92

5. The oxide *B* was found to be pure FeO.

Experiments with Special Cores

6. A series of experiments was made to demonstrate surface burning, by making a very porous core, using sifted sand

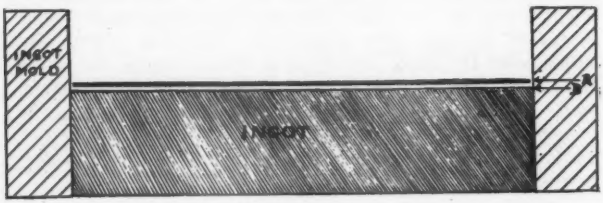

FIG. 1—DIAGRAM OF SURFACE OF STEEL INGOT SHOWING (*A*) OXIDE SURFACE, A MIXTURE OF FERROUS AND FERRIC OXIDES, AND (*B*) THINNER INNER OXIDE SURFACE COMPOSED OF PURE FeO.

free from fines and mixing with it five per cent sodium silicate as a binder. This fastens each sand grain by glassy adhesion, after the core has been baked.

7. This experimental core, 4 x 4 x 2 in., was placed in a large mold. After the steel had been cast against it, the metal was found to have an oxide attached, having a thickness of ¼ in., which had to be pried off the casting.

8. This may be explained by the fact that, due to its permeability, the core absorbed the oxide capillarily as fast as formed, thus cleaning the surface of the metal adjacent to it, so that it was free to burn (act chemically) with all the oxygen it needed until the metal cooled to a temperature where such action ceased. See core *A* in Fig. 2.

9. Another core of the same dimensions as above was made

from zircon (zirconium silicate) bonded with a very small amount of sodium fluoride, producing after ignition at red heat a core that was practically air tight. The core was placed in the mold in the same position as was the original core. The oxide formed on its surface was noticeable only as a few small, black spots.

10. The experimental cores were white in color, and the depth of iron oxide penetration, which is dark brown to black in color, therefore was easily observed in both instances. See core *B*, bonded with zircon, in Fig. 2.

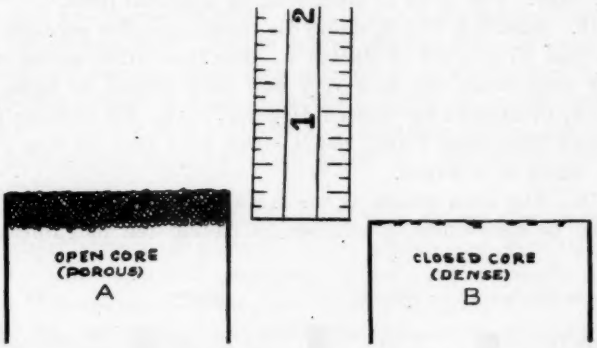

FIG. 2—SLAG ATTACK ON TWO CORES. *(A)* AN OPEN POROUS CORE BONDED WITH 5 PER CENT SODIUM SILICATE; *(B)* ZIRCONIUM SILICATE CORE BONDED WITH SODIUM FLUORIDE PRODUCING A PRACTICALLY AIR-TIGHT MIXTURE. THE RELATIVE AMOUNTS OF OXIDE SURFACES ON THE TWO CORES ARE SHOWN.

Observations

11. Ferrous oxide melts at 2588 degs. Fahr. Inasmuch as the molten steel had a temperature of 2970 degs. Fahr., it is evident that the temperature above 2588 degrees caused the ferrous oxide to be extremely fluid, thus accounting for its filtration through silica washes, and for its absorption by a porous core-sand mixture.

12. There is a secondary chemical action that often takes place between the iron oxide and the silica, depending, of course, on temperatures involved. Sand and iron oxide are substances that are chemically opposite in nature. These tendencies are accentuated by the molten steel in close contact. The reactions

involved may be understood by referring to sketches Nos. 1, 2, 3 and 4 in Fig. 3.

13. Sketch 1, at the left of Fig. 3, represents steel just cast against a core surface. There is an expansion of air in the core, and the flow of air is away and out. The molten steel is illustrated as a heavy, solid line.

14. Sketch 2 of Fig. 3 illustrates the condition a few seconds later than that shown in Sketch 1. The casting surface begins to burn, forming iron oxide. This oxide, as previously stated, melts at 2588 degs. Fahr. and is extremely fluid at the temperature of the metal as cast, which is slightly less than 3000 degs. Fahr. The oxide is illustrated by diagonal lines.

15. Sketch 3, Fig. 3, shows the condition a few seconds later than that illustrated in Sketch 2. The iron oxide reacts chemically with what are now very hot sand grains to form iron silicate, illustrated by crossed diagonal lines. Its melting point is about 1200 degs. Fahr., much lower than that of iron oxide, with which it is mixed.

16. The sand grains at the surface often are eaten off flat, as can be seen under a microscope having ten magnifications.

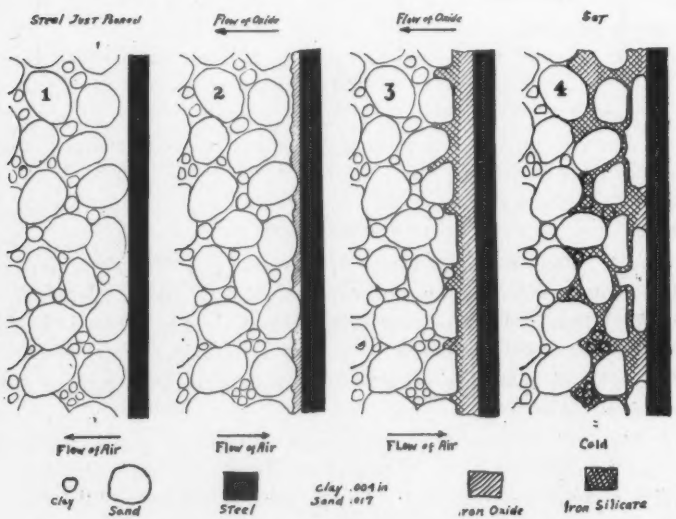

FIG. 3—ILLUSTRATING VARIOUS STAGES OF PENETRATION OF OXIDE INTO CORES.

A flow of the iron oxide-silicate mixture into the core also is illustrated.

17. Sketch 4 of Fig. 3 shows the final core surface, where most of the iron silicate—mixed with ferrous and ferric oxides of iron—is drawn by capillary attraction into the core, in extent depending upon its porous condition. Points of contact show evacuating spaces between these points, all visible under a low-power magnifying glass. Sand from surfaces of steel castings often contains 25 per cent, by weight, of absorbed oxides.

18. It is interesting to find that specimens of core surfaces that peel away from the castings often are found to be magnetic. This does not happen in green sand, but is a common occurrence with baked core sand. As the oxides and the silicates penetrate more deeply into the core, they encounter carbon formed by the destructive action of heat upon the bonding materials used in making the core. This carbon has a reducing action, similar to that in the blast furnace, where oxides are chemically reduced to metallic iron.

19. In the case of dried cores, iron oxides flow into the interstitial spaces between the sand grains and there deposit metallic iron, which is sometimes found as a net-work of the shapes corresponding to the interstices into which it ran. These can be seen microscopically when the mass of a magnetic core is gently crushed and these little iron anchors are separated by a magnet.

20. When the interstitial net-work of metallic iron coalesces, scabs are formed and are often quite large and as far back into the core as one-half inch. To the eye they appear as fused metal with sand adhesions.

21. Should the magnetic surface of a core be broken into three parts, one of which is digested in an alcoholic solution of hydrofluoric acid (1:3) overnight in a warm place and then washed free from acid, the silica will be dissolved, leaving the metallic iron interstitial net-work. A microscope will reveal rounded holes, where the sand grains were originally. The mass is very magnetic. See Sec. 3 of Fig. 4.

22. When one of the other parts is extracted with warm hydrochloric acid to dissolve the metallic iron, interstices may be seen where the metallic iron penetrated it. The mass consists of sand and is non-magnetic, as shown in Sec. 1 of Fig. 4.

23. The third or remaining part represents a conglomera-

tion of the two materials described. This third substance is magnetic because of its iron content. This is illustrated in Sec. 2 of Fig. 4.

DEDUCTIONS

24. The data here reported were assembled in attacking the problem that confronts those who cast steel against sand. It had been thought that the sand used was not refractory enough, and much time and effort were spent to obtain more refractory mixtures.

25. Oxide formation and action should not be overlooked in attempts to solve such problems. Spraying of metal to close

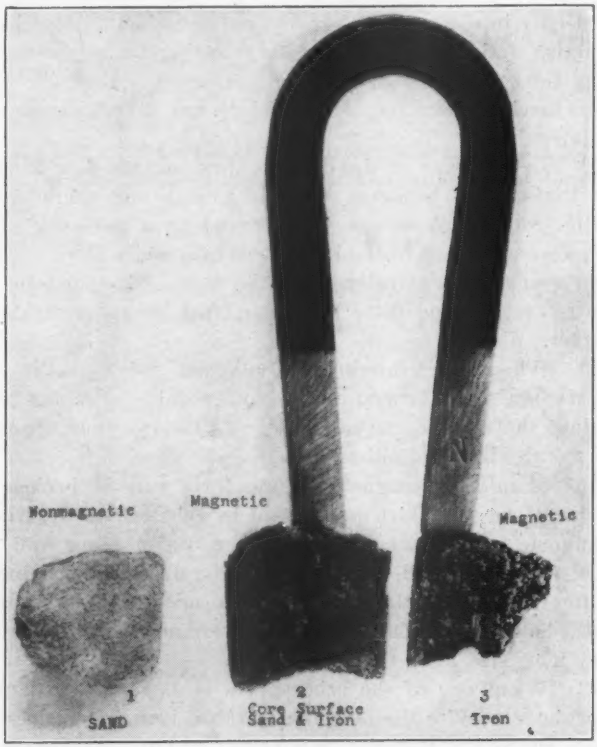

FIG. 4—THE MAGNETIC CHARACTERISTIC OF A CORE SURFACE WITH PENETRATED IRON (SECTION 2) FORMED FROM OXIDE REDUCED BY CARBON OF CORE BINDERS.

core surfaces, exclusion of air, displacement of air with inert gases, and oxidizing agents incorporated in sand mixtures (because higher oxides adhere less tenaciously than does ferrous oxide), are some of the expedients which suggest themselves to the author as meriting investigation.

26. It is hoped that there will be reported to the steel casting industry, results of many researches of more comprehensive and instructive nature than those here presented.

DISCUSSION

ORAL DISCUSSION

A. H. DIERKER:* Mr. Goodale compares the core made with sodium silicate and sand, in which he feels the oxide is formed due to the oxygen getting through the porous sand. Sodium silicate is a hydrate and the heating probably drives off the water. The water in contact with the hot metal probably decomposes the hydrogen and oxygen, and the oxygen liberated from the water probably causes oxidation of the metal just as well as air getting through to the sand itself.

Further on the author finds the oxide is penetrating the sand and there has been reduced back to metallic iron. However, there might be another way in which that could happen.

We ran some experiments on cores, during which we poured a very heavy section of iron around a very small core. In that case we found the penetration of the metallic iron into the core, practically through it. There were spaces filled with iron so fine one would hardly think it possible. We could not see it with the naked eye, but under a microscope we could see very fine threads of metal.

Perhaps in this case some of that metal could have been actual penetration of metal into the sand rather than reduction of the oxide back to the metallic state, especially since it happened so far away from the mold face, where we have a comparatively low temperature. Reduction of iron oxide to metallic iron only takes place at a comparatively high temperature.

A. D. WILSON:† We have found this same phenomena of the steel apparently entering the sand on especially large sections. About 60 to 75 per cent of our work runs from 10 tons to 150 tons to the casting.

Also, we have found that different alloys, especially those used for rolling-mill rolls, have a great deal to do with the amount of metal which apparently enters the sand.

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*Ohio State University, Columbus, Ohio.

†Williams Molding & Foundry Co.

I personally am very thankful to Mr. Goodale for the suggestion that the oxide enters the sand and then breaks down again into metallic iron while in the sand, because it leaves a new field of investigation which I believe every one who makes extremely heavy castings will find it mighty valuable to dig into.

On alloy steels, especially rolls, we have found quite frequently that rolls are almost impossible to clean except by putting them into a lathe and turning a combination of sand and steel from the outside diameter, due entirely to this fact that the metal has permeated the sand.

Considerable work had been done to eliminate that, without getting into the academic part of it. It resulted in closing up the surface of the sand to almost the same condition one has when casting ingots in a chilled mold. It seemed that the more the sand was opened up, the more we had this difficulty of cleaning it.

We had looked, perhaps, for some metallurgical troubles similar to what might be expected from ingots in steel-mill practice, but fortunately these did not show up. Incidentally, in casting most rolling-mill rolls, there very seldom is more than ¾ inch of sand between a chill and the surface of the roll.

A. W. LORENZ:* We have faced this same problem and have adopted a simpler explanation, which may or may not be correct, and which at the same time would not necessarily preclude the possibility of chemical reactions.

Our explanation is merely the infiltration of melted metal. We cast some blocks of steel about 12 inches square and in those blocks we placed a core about two inches in diameter. The cores, of course, were permeated with steel.

It seemed feasible to us that, since the steel was several hundred degrees above its melting point, it was quite possible to heat that internal core to a temperature above the melting point of the steel, and very easy, therefore, for the steel to work in, in its natural state.

That seemed to be verified by the fact that the core, which apparently was insulated in such a way that the heat could not get out, would have that tendency more than would a core in which the heat could escape more readily.

Another factor—not recommended for steel foundry use, but which seemed to have an effect—was the ability of air to escape, as through vents. If the air could not escape, it formed a sort of pressure against the entrance of the steel into the core. Of course, we have to have vents; this is just a little experimental observation we have made.

WRITTEN DISCUSSION

GEO. BATTY:† Mr. Goodale's paper impresses me as being distinctly stimulating and is indicative of lines of procedure that should be

*Bucyrus-Erie Co., South Milwaukee, Wis.
†Steel Castings Development Bureau, Philadelphia.

adopted both in the making of cores and molds for heavy sections or heavy castings. His conclusion that oxide of iron is responsible for what has hitherto largely been considered "infiltration of metal" should lead those of us who have not already arrived at a solution for the trouble into correct avenues of thought and practice.

The pouring speed of large castings, unfortunately, is often too low. In speaking of pouring speed I would suggest, as a definition, "the rise of metal in mold per second." We should understand low pouring speed to have no exact relation to the flow of metal from the ladle, but to the rise of metal in mold. We may have, therefore, many varied pouring speeds in the actual production of a single casting, and as pouring speed decreases, the opportunity for the formation of oxide of iron on the surface of the metal rising in the mold is increased. The oxide film on the surface of the metal tends to fold back upon the mold and upon the cores.

Therefore, we have, in addition to the atmosphere of the sand of the mold and the atmosphere of the cores, an initial liability to the production of the compound which will tend to produce the condition referred to as "burning on."

The capacity of a core or mold to produce oxide of iron is limited by the amount of its interstitial atmosphere. Hence, it becomes obvious that molds and cores for heavy sections should be relatively impermeable —that is, they should have little or no interstitial atmosphere.

This would involve the use of bonding media having a minimum of gaseous product when subject to the thermal attack of cast metal. It would also emphasize the necessity for the impermeable face of the mold and progressively increasing permeability as the distance from the mold-metal interface increases.

Assuming that we are able—and many of us are—to produce these conditions in cores and molds, we are then only subject to the deleterious effects (in the matter under discussion) of oxide of iron deposited on the mold and core faces by the metal rising in the molds. This would lead us to an assumption that mold atmospheres should be made non-oxidizing and that pouring practice should be so modified as to minimize the tendency of air to flow into large molds through one or more risers and out of other risers, as sometimes occurs in the making of large castings.

It is not disputed that examples may be produced of actual metal infiltration in a core of open texture. Particularly is this the case when a relatively small core is almost entirely enveloped by a large body of metal. The ability of the relatively small core to absorb heat is strictly limited, and the opportunity for infiltration under ferrostatic pressure is thereby great.

Mr. Goodale has rendered the industry a marked service in presenting his paper, because it identifies a potent source of trouble. Given a correct diagnosis, we have defined for us a point of attack; and, although I have arrived, along with many other foundrymen, at satisfactory solutions of the burning-on trouble, I may not permit to pass this opportunity to pay tribute to the excellence of this paper.

REPLY BY AUTHOR

PAUL L. GOODALE: With reference to Mr. Dierker's first point, relative to the probability of dissociation of water of hydration from the sodium silicate, my paper contains a statement to the effect that the sand grains were fastened by glassy adhesion. This means that the sodium silicate was vitrified upon the sand grains into inorganic glass. The whole core was heated to redness for a sufficient time, to constant weight before use in these experiments.

With reference to Mr. Dierker's second point—possible penetration of metal into the sand, rather than reduction of oxide back to the metallic state—if this were the case, the metal back of the mold face would have the same chemical composition as the metal cast against it. This was not found to be the case, as shown by Table 1.

Table 1

CHEMICAL ANALYSES OF METAL BACK OF AND CAST AGAINST MOLD FACE

	Metal cast, Per cent.	Metal back of mold face, Per cent.
Carbon	0.18	0.33
Phosphorus	0.010	0.018
Sulphur	0.018	0.033
Manganese	0.75	0.25
Silicon	0.39	1.36
FeO	0.04	1.49

With reference to Mr. Dierker's third point, the reduction of iron oxide takes place only at comparatively high temperatures. The author feels that reduction will take place readily at its melting point, and he would like to call attention to penetration of iron oxide in the sand surfaces of green-sand molds. It is obvious that fluidity of this oxide is requisite to such penetration.

The following experiments no doubt will be of interest in the study of such absorption phenomena:

Three grams of steel were burned in oxygen to determine how much sand its oxide would absorb. It was placed upon an excessive, weighed quantity of sand, contained in a boat. The steel, theoretically, should give an equivalent of 3.86 grams, FeO. It was found that the absorbed sand, plus the oxide, was 6.80 grams. Therefore, fused ferrous oxide will pick up 43 per cent of its weight of hot sand adjacent to it.

Report of Committee on Standard Tests

To the Members of the American Foundrymen's Association:

During the past year the Committee on Tests has had several large problems to engage its attention, in addition to a number of small ones. These problems have had to do with methods for testing those properties of foundry sands not hitherto considered, and the improvement of some already recommended.

In order to expedite work, many of the problems which come before the committee are referred to sub-committees, who can take active charge of the necessary work and report their results to the main committee for discussion and criticism. If approved, they are submitted to the Executive Committee for its approval before presentation of the convention.

Standard Methods of Testing Core Sands and Mixtures

The first of these large problems to be referred to is the development of standard methods of testing core sands and core mixtures. The subject is important, and E. R. Young, chairman of the Sub-Committee on Core Tests, presents his report separately.

Methods for Testing and Comparing Bond Clays

A second large problem, also assigned to a sub-committee, is the formulation of methods for testing and comparing bond clays. While this work is not yet completed, it may not be out of place to say a few words regarding the results thus far accomplished.

For the experiments, a series of 26 clays were selected, about one-third of these being of the bentonite type. These were first made up into mixtures of Ottawa 50 sand, with 3 and 6 per cent clay, respectively. In the case of the bentonites, 1 and 2 per cent clay were also used.

Each of these mixtures was made up with 4, 6 and 8 per cent water, and tested for green permeability, green compression and tensile strength. They were also baked at 150 degs. Cent. and tested for baked permeability and compression.

Additional tests made were for refractoriness (A. F. A. method), dye adsorption, and specific-gravity colloid test.

In so far as the range of moisture and clay content used in the experiments are concerned, the following general deductions appear to be true:

Green Permeability.—Decreases as moisture content or clay content increases.

Green Compression.—Increases with increased clay and with decreased moisture, but results of latter more marked in bentonitic clays.

Green Tensile Strength. Increase in clay or decrease in moisture increases tensile strength. In case of some non-bentonite clays this was large.

Baked Permeability.—This did not show as much variation as green permeability with different clay or water contents, although at times the increase over the green was appreciable.

Baked Compression.—Increased clay or increased water content both increased baked compression.

Dye Adsorption.—In a general way high dye adsorption seemed to indicate high compressive strength in both green and baked condition and vice versa. However, the strongest clay was not the one that showed the highest dye adsorption or vice versa.

Colloid Test.—There appears to be a very general relation between specific gravity colloid test, and dye adsorption.

The work on bond clays is not yet concluded.

Durability

The durability of foundry sand is an important property, and this has also been referred to a sub-committee to develop a method for testing. This sub-committee has a large amount of data on hand and has made a preliminary report to the main committee, but it is not yet possible to make any final recommendation on the subject, as, owing to circumstances over which the sub-committee had no control, their work was temporarily held up.

Hardness Tester

For some time there has been a demand for a standardized method for testing the hardness of molds, as well as a suitable piece of apparatus which can be used to test the hardness of different sands, on surfaces of all positions. In order to get uniform and comparable results, any apparatus used for this purpose should meet certain conditions, and these are set forth in the report presented by H. W. Dietert of the sub-committee.

Fineness Tests

The committee has some minor changes to recommend in making the fineness test, as follows:

(1) It is recommended that the end of the siphoning tube which hangs in the jar, be curved at the lower end with a half-inch radius. This prevents sand being sucked up from the bottom of the jar during siphoning. The jar should be filled sufficiently full so that the level of the water can be lowered exactly five inches, and leave at least one inch of liquid in the botton. The syphon is to be removed from the jar during the settling process.

(2) In those cases where the disintegrated sand shows a large amount of flocculated material remaining in suspension at the end of the settling period, care should be taken not to siphon this off.

(3) If a fineness test of bentonite is to be made, it will probably be sufficient to use five grams.

(4) As the work of the committee progresses, it seems evident that it may become desirable to further subdivide the material now designated as clay by the A. F. A. test.

(5) Some time ago the Test Committee called attention to the fact that a stirrer could be used for disintegrating the sand, instead of a rotary shaker. Since the fineness test is sometimes used for clayey sands and even clays that are difficult to disintegrate completely, it has been found most necessary to supply the cup of the stirrer with three sets of wire baffles, running down the inside of the cup.

Specific Gravity Test for Colloids

Up to the present time, the dye-adsorption method has been recommended as a tentative standard test for measuring colloidal matter in sand or clay. The committee now has under consideration another test which bids fair to give interesting results and which is exceedingly simple.

This is the Bouyoucos specific-gravity test, by means of which the clay or sand is thoroughly disintegrated in water, and then transferred to a high cylinder. After standing for 15 minutes, the specific gravity of the water with suspended fine particles is determined, and from this the percentage of colloidal material can be calculated. No definite recommendation is made regarding this test at the present time.

Compressive Strength Test

It will be recalled that the compressive strength test has been adopted by the A. F. A. as the standard method for testing the strength of sands. There are certain sands and mixtures of very low green bond strength, say, less than one pound per square inch, which call for a rather sensitive apparatus.

After considering the matter, the committee recommends that these shall be tested by compression, since it is possible to construct a machine with sufficient sensitiveness. This is recommended as a tentative standard method.

Standard Sand

For testing work involving cases of careful comparison, the committee feels it desirable to have a grade of sand which shall be regarded as a standard one. It therefore recommends that the standard sand shall be one consisting of rounded grains of silica sand, of such fineness that all passes sieve 40, but none shall pass 100, and that 95 per cent of the grains shall be between 50 and 70. This corresponds to an A. F. A. fineness figure of 50 plus or minus 1.

Pamphlet on Tests

The reception accorded to the pamphlet on tests issued by the A. F. A. in June, 1928, has been most gratifying, and as a result of this the edition has been exhausted. The Sub-Committee on Tests and

the Technical Secretary are now at work revising the pamphlet and bringing it up to date.

In conclusion, the Chairman wishes to express his appreciation for the whole hearted cooperation given by the individual members of the committee, most of whom have been on it since the inauguration of the work. Throughout the eight years of the committee's existence, their interest has never lagged.

Respectfully submitted,

H. RIES, *Chairman*,
Committee on Standard Tests.

DISCUSSION

ORAL DISCUSSION

W. W. KERLIN:* I have found, in the ordinary A. F. A. test for very fine sands—around average grain fineness of 100—that the result always seems a little high to me. That is, it seems like some very fine grains of around 200 to 270 mesh were obtained in the colloidal solution that remained at the top of the glass. Dr. Ries, have you done any work on using a larger volume of water in such tests as this?

DR. H. RIES:** You mean, using a larger jar?

W. W. KERLIN: Yes.

DR. H. RIES: No, we always use the one-quart jar. If there is much colloidal material and it is flocculated, as I said, it has always seemed to me possible for these little flocculated or compound particles to act as life preservers to hold up the fine silt grains. It is then necessary to siphon a shallow depth of water so as not to draw up this flocculated colloidal material.

Some time ago we had a similar question put to us. We found a foundry using a very fine-grain sand. They reported that they could not get uniform results and they sent a sample down to me. I divided it into two portions, kept one-half and sent the other half to C. M. Saeger, Jr., at the Bureau of Standards, Washington. Our duplicates we checked very closely. Of course, we were rather careful in making the tests. I should say that you should not have much trouble.

N. F. MOORE:† We have used a sand 40 to 45 per cent of which goes through the 270-mesh screen. We found it very difficult to standardize our tests on clay content with sands as fine as that, but it is just like many other problems—after tests are run a few times, the troubles work themselves out. We have no trouble now in checking our own results on clay content in those sands. It is just a question of one's own manipulations.

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*Enterprise Sand Co., Fulton Bldg., Pittsburgh.
**Cornell University, Ithaca, N. Y.
†Piston Ring Co., Muskegon, Mich.

We found, in a certain sand, that by varying the settling time we could get a variation in clay content. In one sand we got from 6 to 27 per cent clay by this means. Everyone must standardize his own practice and be satisfied that that is what he wants to use.

DR. H. RIES: To vary the settling time is to depart from the standard method.

N. F. MOORE: We were trying to determine exactly what was the effect of varying the settling time, so as to find out how closely we had to adhere to the actual standard method.

DR. H. RIES: Of course the clay content can be varied by varying the settling time; that is what we are investigating now. I do not want to anticipate that by saying very much about it, but if the standard time called for in the standard method is used, one clay content can be obtained; if the settling period is changed to 15-minute intervals, a different clay content will result. That is self-evident. If the time is increased to 25 minutes, the result is a still different clay content. The longer the settling period, the smaller will be the clay content obtained.

I think it is quite well understood that what we call the A. F. A. clay content is not what ceramic technologists would call "true clay."

N. F. MOORE: The reason we tried these variations was to find out for our own satisfaction how closely we had to adhere to the standard practice. In running those fine sands, suppose our operator, while checking a sample of sand for clay, let it settle a minute too long. I wanted to find out for my own satisfaction how much of an error that might introduce, and to impress upon the operator, also, how careful he must be. We found that we must absolutely adhere to the standard if we want to check our results.

We found another condition, also—that no very clear conception exists in our minds as to just where the fines leave off and the clay starts. That is a thing that has puzzled us greatly.

Report of Sub-Committee on Core Tests

To the Members of the American Foundrymen's Association:

During the past year the Sub-Committee on Core Tests, working under the direction of the Committee on Tests, has disposed of various unfinished items listed as "work in progress" in their report presented to the April, 1929, convention of the A. F. A.

A number of these items have been approved by the sub-committee and by the Committee on Tests for recommendation to the Executive Committee for approval as tentative-standard methods or as tentative-standard specifications, as the case may be. On some few items very little progress has been made during this year, and on others a beginning has been made. The next year should show considerable progress on these items, as the number of problems before the sub-committee has been reduced probably fifty per cent from one year ago.

Test Methods

The principal work of the sub-committee is on test methods. Under this head the following new methods or refinements of existing methods have been approved for recommendation as tentative standards.

Tensile Strength Test Method

The tensile test method has been changed to substitute the use of a predetermined weight measure with a tolerance of height of core of ± 1/64 in. for the use of a volume measure and a cut-off device, as the weight measure was found to give more consistent results.

The question of the relative merits of top ramming and of jolting or jarring for preparing core test specimens was involved here, and our investigation showed top ramming preferable for the tensile test. Top ramming is the present tentative-standard method.

Jaws for Tensile Test Method.—The sub-committee recommends as a tentative-standard method the use of self-aligning jaws for holding the specimen for the tensile test to permit proper application of the load and insure that the specimen breaks in the center and under tension. The nature of the material for jaws and the shape or contour of the gripping surface are still under investigation. The sub-committee may later recommend specifications covering these details.

Compression Test for Weakly Bonded Unbaked Cores

The compression-strength test method with a machine reading to 0.05 lb. is recommended for the testing of weakly bonded core-sand mixtures in the green state.

Core Permeability Testing

The use of the standard A. F. A. permeability specimen for determining the permeability of baked cores or of dried (baked) molding sand is recommended. Directions for the correct procedure to permit use of the A. F. A. permeability machine and specifications for the additional device necessary to carry out the test, have been prepared.

Following is a general description of the core permeability tube used and the procedure for carrying out this test:

The standard A. F. A. permeability specimen is prepared in the usual manner and rammed with the standard permeability rammer. If the specimen is very low in green bond and will not support its own weight upright in the green condition, a split core box (Figs. 1 and 2) is used to replace the standard permeability tube.

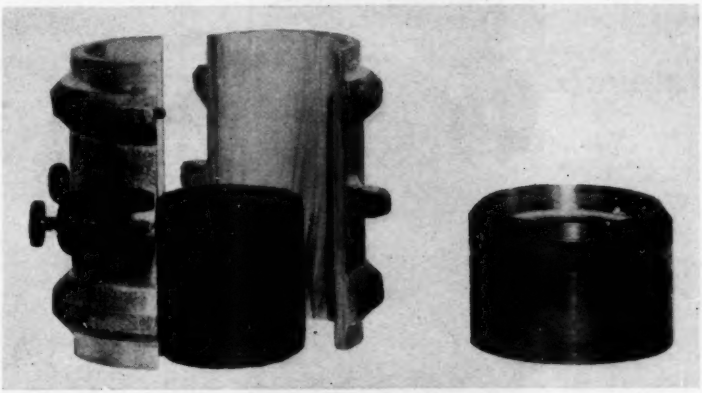

FIG. 1—RECOMMENDED STANDARD CORE PERMEABILITY TUBE. SPLIT CORE BOX (LEFT), WHICH REPLACES STANDARD PERMEABILITY TUBE, CLAMPS TOGETHER TIGHTLY AND IS MACHINED TO FIT INSIDE SPECIAL PEDESTAL (RIGHT). (SEE ALSO FIGS. 2 AND 3.)

This box clamps together tightly and is machined so that one end fits inside a special pedestal or support (*A*, Fig. 2). After ramming, the core may be removed from the split core box and laid horizontally on a dryer for baking.

The baked core is put in the dry permeability tube (Fig. 3), the core resting on a rubber gasket which is ⅛ inch smaller in diameter than the core. The core is held in place by a clamp which extends across the top of the tube, carrying a set screw terminating in a perforated concave disk. The set screw is tightened so that the disk rests against the top of the core.

The tube is provided with internal ribs which hold the core central. The tube is filled with mercury flush with the top of the core.

For handling cores which are quite weak in the baked condition and subject to abrasion of corners and edges, a small steel ring is used. The

ring is rammed up in the core and provides a solid corner surface for handling.

The permeability measurement is taken on an A. F. A. permeability apparatus fitted with a mercury cup, the core permeability tube being placed in the mercury cup in the usual manner.

The accompanying illustrations—Figs. 1, 2 and 3—indicate clearly the construction and use of the core box and core permeability tube.

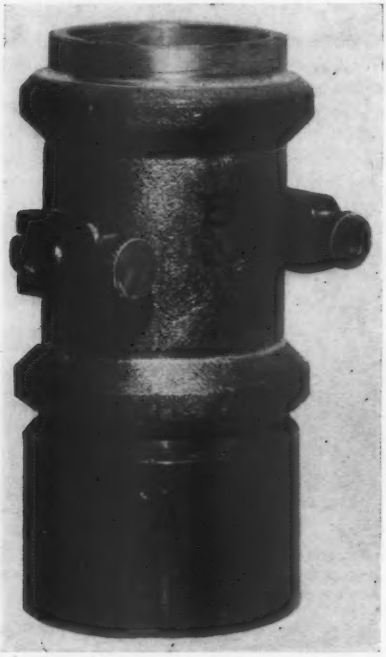

FIG. 2—SPECIAL PEDESTAL OR SUPPORT (A), FOR RECOMMENDED STANDARD CORE PERMEABILITY TUBE. SPLIT CORE BOX (B) IS MACHINED TO FIT INSIDE THIS PEDESTAL. (SEE ALSO FIGS. 1 AND 3.)

SPECIFICATIONS

Standard Laboratory Oven

Very early in the work of this sub-committee it became apparent that the greatest variable in core testing was that of baking conditions. The Committee on Tests instructed the sub-committee to draw up specifications for a standard laboratory core-baking oven which would insure reasonably uniform baking conditions. These specifications have been prepared covering the following items: Source of heat, temperature control, shelf construction, circulation, changes of atmosphere and openings.

Motion was passed and submitted to the Executive Committee for approval, that the following be adopted as tentative standard A. F. A. specifications for a laboratory oven for baking test cores:

(1) *Heat.*

For baking of cores, some source of indirect heat should be supplied capable of providing a maximum temperature of 600 degs. Fahr. for continuous service.

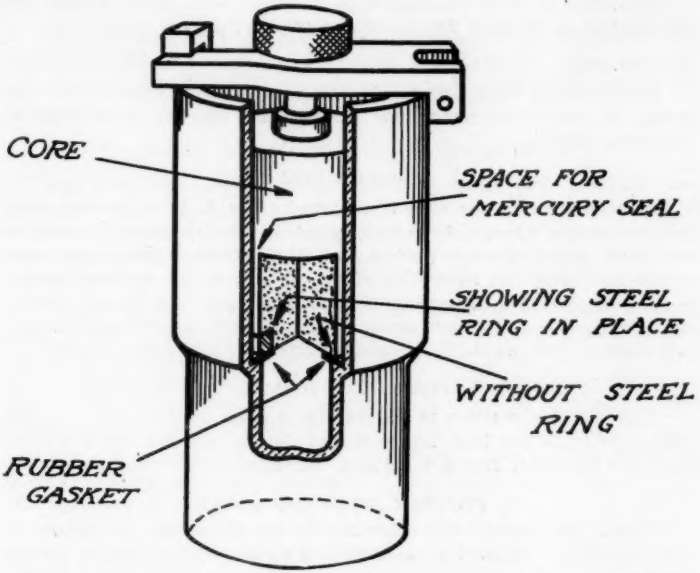

FIG. 3—DRY PERMEABILITY TUBE FOR CORE PERMEABILITY TESTING. BAKED CORE RESTS ON RUBBER GASKET AND IS HELD BY CLAMP, TIGHTENED BY SET SCREW AT TOP. TUBE IS PROVIDED WITH INTERNAL RIBS TO HOLD CORE CENTRAL, AND IS FILLED WITH MERCURY FLUSH WITH TOP OF CORE.

(2) *Temperature Control*

The oven should be equipped with some form of automatic regulator to maintain an even and unform temperature with a temperature variation no greater than plus or minus 5 degs. Fahr., and also a thermometer for indicating the temperature inside the oven. The input of heat must be such that, after putting in the load, the oven shall recuperate to baking temperature in 30 minutes. The thermometer bulb should be located within one inch above the cores in the oven.

(3) *Shelf Construction.*

The oven is to be equipped with one or more revolving shelves to rotate at about 3 to 4 r.p.m. through suitable reduction-gear drive and motor. The revolving shelf should be a perforated steel plate and strong

enough to resist warping when loaded with cores and with dryer plates.

(4) *Circulating Fan.*

The oven is to be provided with a circulating fan to supply the baking chamber with proper circulation of air for proper oxidation of oils during baking period and maintenance of uniform temperature through all parts of the oven.

(5) *Number of Air Changes.*

The oven is to be equipped with sufficient vent ports of such size and location as to allow five to eight changes of air per hour.

(6) *Opening.*

Some opening should be provided to remove baked cores at different periods of time when testing for baking time, without interference of oven temperature.

Standard Sand

A standard sand for core testing and other A. F. A. testing work has been agreed upon, and the recommended tentative standard specification reads as follows: "A washed and dried, rounded grain silica sand with a maximum dye adsorption of 40, all passing the 40-mesh screen; 95 per cent passing a 50-mesh screen and remaining on a 70-mesh screen, and any passing a 70-mesh screen remaining on the 100-mesh screen, this sand to have an A. F. A. fineness number of 50 plus or minus 1."

Standard Test Methods

A standard procedure to govern the making of test cores for sub-committee work has been laid out, and details covering the following items are specified: Measure, mixing, reference binder, sand and water.

Procedure for Testing Cores

Motion was passed and submitted to the Executive Committee for approval, that the following be adopted as standard procedure for making test cores:

(1) *Weight Measure.*

The ingredients of the mixture or test cores shall be measured by weight and may be reported also by volume.

(2) *Mixing.*

The binder, sand and water shall be mixed for 15 minutes in a mixer of the pan muller type or its equivalent. A dummy batch should first be run through the mixer.

(3) *Binder.*

In comparing characteristics of binders, the reference standard binder* shall be raw linseed oil of a quality meeting the A. S. T. M. specifications for such an oil.**

*It is suggested, unless other ranges of strength are required, that the use of a ratio of 100 of sand to 1 of binder by weight, will give an average strength core.

**American Society for Testing Materials, Specification for Raw Linseed Oil D234-28.

(4) *Sand.*

The sand used shall be the standard A. F. A. sand.

(5) *Water.*

The water used shall be distilled water.

UNFINISHED AND FUTURE WORK

Compressibility

The sub-committee has planned an investigation of collapsibility or compressibility and methods of testing this property. The work on this problem scheduled for the past year had to be postponed for the time being.

Surface Hardness Testing and Gas Evolution

Gas Evolution.—Some progress has been made on methods for testing and measuring these properties, but as yet we have nothing to report. We hope, by concentrating on the remaining problems, to have some recommendations ready for presentation to the Executive Committee during the next year.

It may be well, in making our yearly report, to remind the membership that the technical committees confine themselves to investigation and study of properties and methods for testing these properties. They do not undertake research problems of an operating nature, nor make any recommendations on shop practice, no matter how interesting these problems are in themselves.

Sometimes their work requires investigation of a general nature in defining testing methods—for example, last year's work was done on the influence of moisture content on core strength, and on the influence of the type of ramming—but they do not report these as investigations of these particular problems.

The text of the detailed tentative-standard methods and changes in methods, and of the specifications mentioned earlier, will appear in the new edition of the sand-test pamphlet and is printed as Appendix "A" to this report. The data accumulated in sub-committee tests, and which have guided us in our recommendations, appear as Appendix "B" to this report.

In conclusion, the chairman wishes to acknowledge the hearty co-operation of the sub-committee members and to especially mention the work of A. C. Jones on investigation of the tensile test, the work of H. W. Dietert on core-permeability testing, the work of Frank Valtier in the standard oven and the work of C. M. Saeger, Jr., on the testing of low green-bond-strength mixtures.

Respectfully submitted,

EDWARD R. YOUNG, *Chairman*,
Sub-Committee on Core Tests.

APPENDIX "A"

(From Minutes of committee meetings)

TENSILE STRENGTH TEST METHOD

The following motions were adopted and submitted to the Executive Committee for approval:

> "That the tensile test method be changed to substitute the use of a predetermined weight measure, with a tolerance of height of core specimen of plus or minus 1/64 in., for the use of the cut-off method, for securing the proper height of test specimen."
>
> "That the committee recommends as a tentative standard, the use of self-aligning jaws in connection with the tentative standard tensile strength test for cores."

COMPRESSION TEST FOR WEAKLY BONDED UNBAKED CORES

The following motion was passed and submitted to the Executive Committee for approval:

> "That the committee recommends the compression test method for testing low-strength mixtures with a machine reading to 0.05 lb. per sq. in., and that a footnote be added to the description of the Saeger spring compression machine stating that the machine can be equipped for testing low-strength mixtures."

CORE PERMEABILITY TESTING

The following motion was passed and submitted to the Executive Committee for approval:

> Dry permeability tube for testing permeability of baked cores or dried molding sand, using standard A. F. A. permeability.—"Dry permeability tests shall be made on the standard permeability specimen which has been dried or baked. The curved surfaces shall be covered air-tight for making the test, and the air pressure from the permeability apparatus shall be so applied that the air passes lengthwise only through the specimen. Care must be taken to see that no air passes through or along the outside of the curved surface of the specimen. Any device for making this test shall cover no more than 13 per cent of each or either of the plane surfaces of the specimen."

APPENDIX "B"

COMPARISON OF TENSILE TEST METHOD WITH CUT-OFF DEVICE AND WITH USE OF DEFINITE WEIGHT OF SAND WITHOUT CUT-OFF DEVICE[1]

The data presented herewith represent a comparison between the tensile test method when using a cut-off device, and the method when

[1]Tests submitted by A. C. Jones, Lebanon Steel Foundry, Lebanon, Pa.

using a definite weight of sand which, when impacted, will produce briquets one inch thick.

A. CORE SAND WITH CONSIDERABLE GREEN BOND

In an effort to emphasize or exaggerate any variation in results that might be effected, a sand of considerable green bond was made in a 9-foot American clay pan mill and mulled for 10 minutes. The mixture used was as follows:

	Quarts.
Heap sand	300
Wheat flour	10
Dextrine	5
Bentonite	5

The molding properties of this mixture were as follows:

Moisture, per cent	5.2
Cohesiveness (A. F. A. bar), grams per 2 sq. in	186
A. F. A. permeability	163

Table 1

RESULTS OF TEST NO. 1-A: STANDARD SINGLE SPECIMEN, WITH CUT-OFF AND FULL HOPPER

Specimen No.	Section, in.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	1.0	73.2	6.9—	...
2	1.0	69.3	11.8—	...
3	1.0	84.9	8.0+	78.6
4	1.0	83.4	6.1+	...
5	1.0	82.2	4.6+	...
6	1.0	78.6	...	...
Avg.		78.6	6.2	

Six specimens were made for each of the following three phases of this particular investigation:

No. 1-A. Standard tensile, using cut-off, and as directed in recent sand pamphlet.*

No. 2-A. Standard tensile, without cut-off, but using a definite weight of sand to give a 1-inch section core within a tolerance of plus or minus 0.02 inch.

No. 3-A. Standard tensile, using cut-off as in No. 1-A above, but using just enough sand to have the specimen, before cutting off, measure 1.10 inch. This was done so as to note a possible difference even with a cut-off, as the result of varying amounts of sand after impacting, above the 1-inch level.

*_Standard and Tentatively Adopted Methods of Testing and Grading Foundry Sands_, A. F. A. (1928), p. 64.

Table 2

RESULTS OF TEST NO. 2-A: STANDARD SINGLE SPECIMEN, WITH DEFINITE WEIGHT (92 GRAMS), NO CUT-OFF

Specimen No.	Section, in.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	1.0 x0.985	86.1	0.2—	...
2	1.0 x1.0	89.0	3.1+	83.9 (Incl. No. 4)
3	0.99x1.0	84.3	2.3—	...
4	0.99x1.0	*72.0	...	86.3 (Elim. No. 4)
5	0.99x1.0	90.3	4.6+	...
6	1.0 x1.0	81.9	5.0—	...
Avg.		86.3	3.1	

*Not included in averages.

All of the specimens were baked at 400 degs. Fahr. for one hour. While accumulating a sufficient number of specimens for a bake, the specimens were covered with a beaker moistened on the inside. A 24x 18x15 inch Estate fresh-air oven was used with a Robertshaw automatic temperature regulator.

For these tests, results of which are shown in Tables 1, 2 and 3, the bottom of the oven was loaded with about 75 lbs. of steel, to reduce the drop in temperature when the charge of specimens was introduced.

A standard Wadsworth core tensile machine was used. The standard grips were replaced with special ones which we made, incorporating rollers of ½-inch diameter at the four engaging points where contact is made with the core. The pins in which the rollers turned were of 7/32-inch diameter.

Retests

A retest of phase No. 1-A was made, using the same mixture as on the original test, and results of the retest are shown in Table 4. Of course, the nature of the heap sand probably was changed, since there was an interval of three months between the original test and the retest. Retests of phases 2-A and 3-A are shown in Tables 5 and 6.

Table 3

RESULTS OF TEST NO. 3-A: STANDARD SINGLE SPECIMEN, WITH CUT-OFF, SO THAT THICKNESS OF SPECIMEN, AFTER IMPACT, BUT BEFORE CUTTING OFF, WAS 1.10 INCH

Specimen No.	Section, in.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	1.0x1.0	84.3	11.5+	...
2	1.0x1.0	67.2	11.1—	...
3	1.0x1.0	70.8	6.4—	75.6
4	1.0x1.0	81.3	7.5+	...
5	1.0x1.0	66.6	11.9—	...
6	1.0x1.0	83.4	10.3+	...
Avg.		75.6	9.8	

Table 4

RESULTS OF RETEST NO. 1-A: STANDARD SINGLE SPECIMEN, WITH CUT-OFF AND FULL HOPPER

Specimen No.	Section, in.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	1.0	55.5	3.3—	...
2	1.0	58.2	1.4+	...
3	1.0	48.3	15.8—	57.4
4	1.0	57.6	0.3+	...
5	1.0	70.2	22.3+	...
6	1.0	54.6	4.9—	...
Avg.		57.4	8.0 (Incl. Nos. 3, 5)	
Avg.		56.5	2.5 (Elim. Nos. 3, 5)	

Table 5

RESULTS OF RETEST NO. 2-A: STANDARD SINGLE SPECIMEN, WITH DEFINITE WEIGHT (92 GRAMS), NO CUT-OFF

Specimen No.	Section, in.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	1.0x1.0	63.0	2.3—	...
2	1.0x1.015	44.0	...	...
3	1.0x0.99	68.2	5.7+	64.5
4	1.0x1.0	63.3	1.9—	...
5	1.0x0.98	63.7	1.2—	...
6	1.0x1.0	64.2	0.5—	...
Avg.		64.5	2.3 (Elim. No. 2)	

Table 6

RESULTS OF RETEST NO. 3-A: STANDARD SINGLE SPECIMEN, WITH CUT-OFF, SO THAT THICKNESS OF SPECIMEN AFTER IMPACT, BUT BEFORE CUTTING OFF, WAS 1.10 INCH

Specimen No.	Section, in.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	1.0	64.8	2.0—	...
2	1.0	65.4	1.1—	...
3	1.0	65.7	0.6—	66.1
4	1.0	71.1	7.6+	...
5	1.0	72.0	8.9+	...
6	1.0	57.9	12.6—	...
Avg.		66.1	5.5	

Table 7

(MOISTURE OF OIL SAND, 7.7 PER CENT)

RESULTS OF TEST NO. 1-B: STANDARD SINGLE SPECIMEN, WITH CUT-OFF AND FULL HOPPER

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	107.1	1.3+	....
2	93.1	12.0—	....
3	102.0	3.8—	105.7
4	107.7	2.1+	....
5	119.4	12.9+	....
6	104.7	1.1—	....
Avg.	105.7	5.5	

Table 8

(MOISTURE OF OIL SAND, 7.7 PER CENT)

RESULTS OF TEST NO. 2-B: STANDARD SINGLE SPECIMEN, WITH DEFINITE WEIGHT (100 GRAMS), NO CUT-OFF

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	107.7	0.2—	....
2	114.9	6.5+	....
3	108.9	0.9+	....
4	115.8	7.3+	107.9
5	104.4	3.2—	....
6	95.4	11.6—	....
Avg.	107.9	4.95	

Table 9

(MOISTURE OF OIL SAND, 7.7 PER CENT)

RESULTS OF TEST NO. 3-B: STANDARD SINGLE SPECIMEN, WITH CUT-OFF, SO THAT THICKNESS OF SPECIMEN AFTER IMPACT, BUT BEFORE CUT-OFF, WAS 1.10 INCH

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	129.3	2.7+	....
2	116.7	7.3—	....
3	126.9	0.8+	125.9
4	122.4	2.7—	....
5	132.0	4.8+	....
6	127.8	1.5+	....
Avg.	125.9	3.3	

B. CORE SAND WITH LOW-GREEN-BOND OIL SAND

The preceding tests were repeated using a mixture of 1 to 50 by volume of raw linseed oil and Goldman's fine washed and dried silica sand. This sand has the following fineness characteristics:

Sieve No.	Per cent remaining on screen.	Sieve No.	Per cent remaining on screen.
6	....	100	43.2
12	0.01	140	17.5
20	0.13	200	3.3
40	1.2	270	0.6
70	33.2	Pan	0.7

The specimens were baked at 400 degs. Fahr. for 1¼ hours, and the results of tests on oil-sand cores having low green bond and 7.7 per cent moisture are shown in Tables 7, 8 and 9.

Discussion

It appears as though the method—using a definite weight of sand to give a one-inch briquet within the tolerances mentioned (plus or minus 0.02 inch), and eliminating the cut-off—gives more uniform results on material that has relatively high green bond. The cut-off probably has some influence; but with a variable amount of sand, taken to fill the hopper each time a briquet is made, a variable impacting is obtained because of the cushioning effect of the different thickness of sand obtained after the first blow.

In both the original test and retest on No. 2-A, we eliminated from the average variation one result which seemed too low to justify its being considered.

With the low-green-bond-strength oil sand it was difficult to note any significant advantage with or without the cut-off. The definite weight seemed to help even where a cut-off was used, as shown in Test No. 3-B (Table 9).

Since sands of considerable green bond may be tested for baked strength, the results in this report seem to favor a method involving a definite weight of sand to give a briquet after impacting that will come to one inch within a tolerance of plus or minus 0.02 inch, and not using a cut-off.

COMPARISON OF TENSILE AND TRANSVERSE TEST METHODS FOR DETERMINING STRENGTH OF BAKED CORES[2]

In these tests, two comparisons were made, namely, (a) a comparison of tensile and transverse methods, and (b) a comparison of jolting with ramming. Results of these tests with varying moisture contents, are shown in Tables 10-15, inclusive.

A large batch of washed and dried Goldman's 00-R sand (same as used in the foregoing tests) was made, with raw linseed oil in proportion

[2]Tests submitted by A. C. Jones, Lebanon Steel Foundry, Lebanon, Pa.

Table 10

(OIL ONLY—NO MOISTURE)

RESULTS OF TEST NO. 1: TENSILE, NO CUT-OFF, USING DEFINITE WEIGHT (95 GRAMS) AND STANDARD RAMMER

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	130.2	0.1—	....
2	141.0	8.5+	....
3	132.9	1.8+	130.4
4	117.0	10.0—	....
Avg.	130.4	5.1	

RESULTS OF TEST NO. 2: TENSILE, JOLTING, WITH CUT-OFF

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	144.9	5.2+	....
2	135.0	2.0—	....
3	137.1	0.5—	137.8
4	134.1	2.7—	....
Avg.	137.8	2.6	

RESULTS OF TEST NO. 3: CAMPBELL'S TRANSVERSE

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	54.9	0.8—	....
2	54.6	1.0—	55.2
3	50.7	8.1—	....
4	60.6	9.0+	....
Avg.	55.2	4.7	

of 1 to 50 by volume. Smaller batches were made from this with varying moisture contents (aiming at 2, 4, 6, 8 and 10 per cent). These batches were mixed by hand 16 hours before being used.

The jolting of the tensile specimen was accomplished with Campbell's jolter* using a special clamp to hold the core box in place and steady. Fifteen jolts were given each specimen.

The baking was done in the laboratory oven mentioned earlier in this report, 400 degs. Fahr. for 1¼ hours being the schedule applied. Each series of the same moisture content was baked at the same time.

*_Standard and Tentatively Adopted Methods for Testing and Grading Foundry Sands_, A. F. A. (1928), p. 68.

Table 11

(2 PER CENT MOISTURE; ACTUAL 2.4 PER CENT)

RESULTS OF TEST NO. 1: TENSILE, NO CUT-OFF, USING DEFINITE WEIGHT (95 GRAMS) AND STANDARD RAMMER

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	117.9	2.0+	....
2	113.4	1.9—	....
3	113.1	2.1—	115.6
4	117.9	2.0+	....
Avg.	115.6	2.0	

RESULTS OF TEST NO. 2: TENSILE, JOLTING, WITH CUT-OFF

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	105.6	0.6—	....
2	98.4	7.5—	106.3
3	108.9	2.4+	....
4	112.5	5.8+	....
Avg.	106.3	4.1	

RESULTS OF TEST NO. 3: CAMPBELL'S TRANSVERSE

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	37.5	3.6—	....
2	39.3	0.1+	....
3	41.4	6.4+	38.9
4	37.5	3.6—	....
Avg.	38.9	3.6	

Table 12

(4 PER CENT MOISTURE; ACTUAL 4.2 PER CENT)

RESULTS OF TEST NO. 1: TENSILE, NO CUT-OFF, USING DEFINITE WEIGHT (95 GRAMS) AND STANDARD RAMMER

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	108.9	4.6—	....
2	98.1	14.0—	....
3	132.0	15.7+	114.1
4	117.6	2.9+	....
Avg.	114.1	9.3	

RESULTS OF TEST NO. 2: TENSILE, JOLTING, WITH CUT-OFF

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	103.2	2.3+	....
2	99.9	1.0—	....
3	101.1	0.2+	100.9
4	99.6	1.5—	....
Avg.	100.9	1.2	

RESULTS OF TEST NO. 3: CAMPBELL'S TRANSVERSE

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	40.5	1.2—	....
2	39.6	3.5—	....
3	41.1	0.3+	41.0
4	42.9	4.7+	....
Avg.	41.0	2.4	

Table 13

(6 PER CENT MOISTURE; ACTUAL 6.1 PER CENT)

RESULTS OF TEST NO. 1: TENSILE, NO CUT-OFF, USING DEFINITE WEIGHT (95 GRAMS) AND STANDARD RAMMER

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	96.9	0.8—	....
2	97.5	0.3—	....
3	99.6	1.8+	97.8
4	96.6	1.1—	....
Avg.	97.8	1.0	

RESULTS OF TEST NO. 2: TENSILE, JOLTING, WITH CUT-OFF

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	101.4	15.9+	....
2	61.8	29.3—	....
3	101.1	15.7+	87.4
4	95.5	2.2—	....
Avg.	97.4	15.8	

RESULTS OF TEST NO. 3: CAMPBELL'S TRANSVERSE

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	38.7	3.2+	....
2	37.2	0.8—	....
3	37.8	0.8+	37.5
4	36.3	3.2—	....
Avg.	37.5	2.0	

Table 14

(8 PER CENT MOISTURE; ACTUAL 7.7 PER CENT)

RESULTS OF TEST NO. 1: TENSILE, NO CUT-OFF, USING DEFINITE WEIGHT (95 GRAMS) AND STANDARD RAMMER

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	107.7	0.1—	....
2	114.9	6.6+	....
3	108.9	1.0+	107.8
4	115.8	7.5+	....
5	104.4	3.1—	....
6	95.4	11.6—	....
Avg.	107.8	5.0	

RESULTS OF TEST NO. 2: TENSILE, JOLTING, WITH CUT-OFF

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	123.0	2.5—	....
2	129.9	3.1+	....
3	114.9	8.8—	126.1
4	136.5	8.0+	....
Avg.	126.1	5.6	

RESULTS OF TEST NO. 3: CAMPBELL'S TRANSVERSE

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	40.8	4.6—	....
2	41.1	4.0—	42.8
3	44.1	3.0+	....
4	45.3	5.8+	....
Avg.	42.8	4.3	

Table 15

(10 PER CENT MOISTURE; ACTUAL 9.5 PER CENT)

RESULTS OF TEST NO. 1: TENSILE, NO CUT-OFF, USING DEFINITE WEIGHT (95 GRAMS) AND STANDARD RAMMER

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	114.6	0.9—	....
2	109.5	5.3+	115.6
3	114.0	1.5—	....
4	124.5	7.8+	....
Avg.	115.6	3.9	

RESULTS OF TEST NO. 2: TENSILE, JOLTING, WITH CUT-OFF

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	105.6	6.6—	....
2	111.9	1.0—	....
3	117.0	3.4+	113.1
4	117.9	4.2+	....
Avg.	113.1	3.8	

RESULTS OF TEST NO. 3: CAMPBELL'S TRANSVERSE

Specimen No.	Load, lbs. per sq. in.	Variation, per cent.	Average.
1	46.2	4.5+	....
2	41.1	7.1—	....
3	43.8	0.9—	44.2
4	45.9	3.6+	....
Avg.	44.2	4.0	

COMPARISON OF STRENGTH VALUES BY TENSILE AND TRANSVERSE TESTING EQUIPMENT, AND NOTING ADVANTAGE FOR EITHER IMPACTING OR JOLTING IN TENSILE TEST

Tabulating the results for each test method and sample of sand, including the average variation from the mean or average value, a fair idea is obtained of the relation between the test methods. The results of the tests are shown in the composite tabulation of Table 16.

Table 16

(OIL ONLY—NO MOISTURE)

COMPARISON OF STRENGTH VALUES BY TENSILE AND TRANSVERSE TEST METHODS

Batch.	Values.	Tensile Test—Definite weight, no cut-off.	Tensile Test—Jolting, with cut-off.	Campbell's transverse test.
No moisture	Average strength, lbs. per sq. in.....	130.4	137.8	55.2
	Average variation	5.1%	2.6%	4.7%
2.4% moisture	Average strength, lbs. per sq. in.....	115.6	106.3	38.9
	Average variation	2.0%	4.1%	3.6%
4.2% moisture	Average strength, lbs. per sq. in.....	114.1	100.9	41.0
	Average variation	9.3%	1.2%	2.4%
6.1% moisture	Average strength, lbs. per sq. in.....	97.8	87.4	37.5
	Average variation	1.0%	15.8%	2.0%
7.7% moisture	Average strength, lbs. per sq. in.....	107.8	126.1	42.8
	Average variation	5.0%	5.6%	4.3%
9.5% moisture	Average strength, lbs. per sq. in.....	115.6	113.1	44.2
	Average variation	3.9%	3.8%	4.0%
	GRAND AVERAGE VARIATION..	4.4%	5.5%	3.5%

The results of Table 16 show that the transverse test is equally as satisfactory as the tensile test for determining the strength of baked cores. They also offer further evidence of the superiority of the weight measure without cut-off, to the volume measure with cut-off device, for making tensile test specimens.

NOTE: For purposes of simplicity, the committee changed the height tolerance from plus or minus 0.02 inch to plus or minus 1/64 inch.

COMPRESSION TEST FOR DETERMINING GREEN BOND OF CORE-SAND MIXTURES

Tests to check the suitability of the compression test method for determining the green-bond strength of low-strength core-sand mixtures, are shown below, with test results given in Table 17. The Saeger compression machine, with a special spring, was used.

Compression Machine for Testing Weak Core-Sand Mixtures[2]

The division of the scale is made as follows: 11 in. ÷ 16 = 1 lb. per sq. in. compressive strength. The scale is divided into pounds and tenths of a pound per square inch compressive strength, and can be read to hundredths of a pound per square inch compressive strength.

[2]Tests submitted by C. M. Seager, Jr., U. S. Bureau of Standards, Washington.

Table 17

CORE-SAND MIXTURES TESTED

	Parts by Volume				Compressive strength,
Mix No.	Downer sand.	Shore sand.	Linseed oil.	Wheat flour.	lbs. per sq. in.
I	40	0	1	0	0.60
					0.70
					0.68
					0.66 Avg.
II	99	0	1	0	0.50
					0.50
					0.45
					0.48 Avg.
III	0	99	1	0	0.26
					0.25
					0.27
					0.26 Avg.
IV	29	0	1½	1½	1.05
					1.00
					1.05
					1.03 Avg.

Remarks

The machine which produced the results shown in Table 17 measures accurately the compressive strength of weak cores and has a range up to 7 lbs. per sq. in. Results of tests made on this same machine by another investigator[4] are shown in Table 18.

[4]Tests submitted by H. W. Dietert, U. S. Radiator Corp., Detroit.

Table 18

COMPRESSION TEST VALUES OF VARIOUS SAND MIXTURES

(SPRING OF COMPRESSION MACHINE FOR VALUES 0 TO 5 LBS.)

Mix.	Linoil.	Moisture.	Green compression.
75% Michigan City 25% Bank sand	1 to 56	4%	0.4 lbs.
35% Bank sand 65% Michigan City	1 to 56	5%	0.5%
100% Michigan City	1 to 56	4%	0.3 lbs.
15% Bank sand 0.5% Bentonite 84.5% Michigan City (Dry hand mixed)	1 to 56	...	0.5%
15% Bank sand 0.5% Bentonite 84.5% Michigan City (Simpson mixed)		...	0.9%
15% Bank sand 0.5% Bentonite 84.5% Michigan City (Wet hand mixed)		40 c.c.	0.5 lbs.
15% Bank sand 0.5% Bentonite 84.5% Michigan City (Simpson mixed)		...	0.9 lbs.
15% Bank sand 0.75% Bentonite 84.25% Michigan City		4%	0.6 lbs.

CORE PERMEABILITY INVESTIGATION

Two tests were performed under this phase of investigation, showing the slight effect on permeability value occasioned by closing off part of the end surface of the permeability specimen, thus reducing the area exposed to air. Results of these two tests are shown in Table 19.

Table 19

TESTS TO DETERMINE EFFECT OF REDUCING AREA OF AIR-ENTRANCE-SURFACE OF PERMEABILITY SPECIMEN

TEST A:[5]

		Permeability.
(1)	Specimen rammed and tested in standard manner.....	253
(2)	Ramming specimen in standard manner, then placing two pennies on top of specimen while testing for permeability	253
(3)	Same as (2), except covering specimen with 50-cent coin when testing for permeability.....	253
(4)	Ramming with one blow of standard rammer, then placing two pennies on top of specimen and giving two additional blows with standard rammer.....	243
(5)	Same as (4), except 50-cent piece substituted for the two pennies	237

TEST B:[6]

	Permeability (Standard method)	Permeability (Partly closed top or bottom of specimen
Sand A	60	55*
B	53	56†
C	41	40†
D	73	67†
E	65	58†
F	54	52†

[5]Data submitted by R. F. Harrington, Hunt-Spiller Mfg. Corp., Boston.

[6]Data submitted by Dr. H. Ries, Cornell University, Ithaca, N. Y.

*Four pennies placed on top of specimen after one ram, then specimen given the standard two additional rams.

†Four pennies placed on bottom of specimen.

NOTE: The pennies were placed on or at bottom of specimen after one ram in order that with the additional two rams, the sand would be packed closely around the coins.

The data of the tests shown in Table 19, as performed by Dr. H. Ries and R. F. Harrington, show the small effect on permeability readings of closing off a part of the surface of the test specimen to the passage of air. The air probably by-passes immediately around the blocked surface, so that only a very small *volume of sand* is eliminated from the test, although the *surface area* closed off is a fairly large per cent of the end-surface area.

These results indicated to the committee that the effect of the rubber gasket in the core permeability tube, although it decreases the end-surface area approximately 13 per cent, would not significantly change the permeability volume.

DISCUSSION

ORAL DISCUSSION

MEMBER: We have had occasion to do some permeability testing a number of times, and we find difficulty in making these tests on cores—difficulty in ramming, also in making permeability tests—when we use a washed sand or the coarser core sand that is being used. I cannot see why permeability tests cannot be small so that we can get away from dipping.

E. R. YOUNG:* The effort of the committee for several years has been to stick to the standard A. F. A. specimens so that the permeability figures will be interchangeable for green sand, for dry sand and for baked cores.

W. A. RENGERING:** Referring to the question concerning the apparent tendency of the A. F. A. clay test to carry off some of the fine silica when siphoning very fine-grained sand samples, I assume that these people are having difficulty in running the A. F. A. clays as routine tests. If one takes the same type of sand, from the same producer, and is running clay tests on carload after carload, one ought to have approximately the same type of clay in each carload of sand.

I have used dye-adsorption tests for that particular purpose with very good results, and I have actually tested carloads of sand with dye-adsorption tests purely as a novelty. Of course, I eventually came back to the A. F. A. method.

However, I do believe that if one establishes his constant where one per cent of clay equals so many grams of adsorbed dye, one will be able to determine the clay in the same type of sand in a future shipment, by this method.

R. F. HARRINGTON:† I believe Mr. Rengering is perfectly correct in his assumption, particularly as he bases his statement on the fact that one would be comparing carload after carload from the same deposit of sand.

For a great many years we have established a definite ratio between dye adsorption and quality of the clay. We set a standard, for example, of one thousand units of dye adsorption on a particular type of sand, and we maintain this from shipment to shipment. I believe it quite worth while.

W. A. RENGERING: I believe one could spend a great deal of time determining the true percentage of clay in his first carload of sand, or sample of sand, and from then on his troubles would be over as regards drawing off these fine particles.

R. F. HARRINGTON: That is very worthy of consideration.

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*Climax Molybdenum Co., Detroit.

**Cincinnati Milling Machine Co., Cincinnati.

†Hunt-Spiller Mfg. Corp., Boston.

Report of Sub-Committee on Mold Permeability and Hardness

To the Members of the American Foundrymen's Association:

The Sub-Committee on Mold Permeability and Hardness is pleased to report excellent progress. An extension tube has been devised which may be attached to an A. F. A. permeability apparatus to measure the surface permeability of a mold.

This tube consists of a half-inch inside diameter rubber tube, three feet in length. On one end is a cast-aluminum cup which fits over a rubber stopper or mercury-seal cup of permeability apparatus. On the other end of this tube is a special-shaped rubber tip. This rubber tip is pressed against the mold surface. The resistance to flow of air through the mold surface is registered on a pressure manometer of permeability apparatus, and is read in permeability units.

The mold-permeability extension tube provides a means for carrying out mold-permeability investigations.

To test the interior mold permeability, the sub-committee is studying an extension tube equipped with a ⅛-inch diameter hollow-wire point. This special tip is used very similarly as one would use a vent wire. The tip is pressed into the mold at various depths, thus making it possible to determine the permeability at various points in a mold.

The sub-committee wishes to continue its study of mold permeability before recommending either of these tubes for tentative standards.

The work on mold hardness has progressed to a point where we have recommended for tentative standard a specification for mold-hardness testing, as follows:

> "A device for determining the mold hardness shall measure the depth of penetration of a rounded-nose plunger 0.2 inch in diameter, having the load applied in the direction perpendicular to the mold surface. The device shall be equipped with an instrument that will indicate in thousandths of an inch the penetration of the plunger into the mold surface. A standard load of 237 grams shall cause a movement of the plunger of 0.1 inch."

In making these recommendations the sub-committee has borne in mind that the mold-hardness tester must be a small, practical, pocket-size instrument, very rapid and accurate in operation and not defacing the mold surface excessively. These requirements have been met, and a hardness tester is now on the market meeting the specifications.

The sub-committee is now at work on developing a hardness tester for dry sand molds.

Respectfully submitted,

H. W. Dietert, *Chairman*,

Sub-Committee on Mold Permeability and Hardness.

Report of Committee on Grading

To the Members of the American Foundrymen's Association:

The grading classifications that were tentatively adopted some time ago have been gradually finding wider use by foundries and sand producers. While a number of foundries are specifying sands according to grain and clay classes, it appears that more are using grain-fineness numbers and clay contents directly and then allowing certain specified tolerances.

The grading system has had a direct influence on sand producers, providing an incentive for producing uniform products. In their efforts to keep within grade limits and to meet specifications, producers have developed methods of controlling their sands, so that in general they are more uniform than ever before. It now is quite possible to buy sands of certain grain-size and clay-content specifications.

This improvement in conditions has benefited all users of sand alike, whether they employ the grading system in their orders or not. Of course, the full value of the system can be had only when foundries and sand producers both use the same system.

Grain Shape—Compound Grains

About two years ago the subject of sand grain shape was considered by the committee and standard classifications were recommended and adopted. These were: Angular, sub-angular and rounded classes.

While these classes cover the primary shapes found in nature, it was noted that some sands contain aggregates of grains, so firmly cemented together that they behave as unit grains. Such aggregates fail to break up in making the standard fineness and clay tests, so the grains are retained on coarser sieves than would be the case if reduced to their primary particles.

The committee has recommended that such aggregates be called *Compound Grains* and that such a class be included in the grain shape classification. Fig. 1 illustrates compound grains.

Present Fineness Classification

There has been some discussion as to the advisability of changing the multipliers used in calculating grain fineness. It was proposed to use multipliers half way between the mesh number of the sieve through which a fraction of sand was passed and that of the sieve on which it is retained.

While certain advantages would be obtained by such a change, it was thought by the committee that these advantages would be outweighed by disadvantages, particularly the confusion that would result in a shift of fineness values now in use. Furthermore, a proposal to create supplementary grading zones to care for those sands which lie sometimes in one zone and sometimes in the adjoining zone, was tabled pending receipt of further information indicating need for such classes.

Advancement of Present Grading System to Standard

The present system of grading has had the rank of tentative standard for at least two years—part of it, for three years. The committee has passed a motion requesting the Executive Committee and the Board of Directors of the A. F. A. to make it a standard method. This has been approved by the Executive Committee.

Grain Distribution

By the term, "grain distribution," we mean the variation or uniformity in particle sizes found in a sand. Table 1 shows sieve analyses on four sands that differ widely in grain distribution, sand No. 1 being

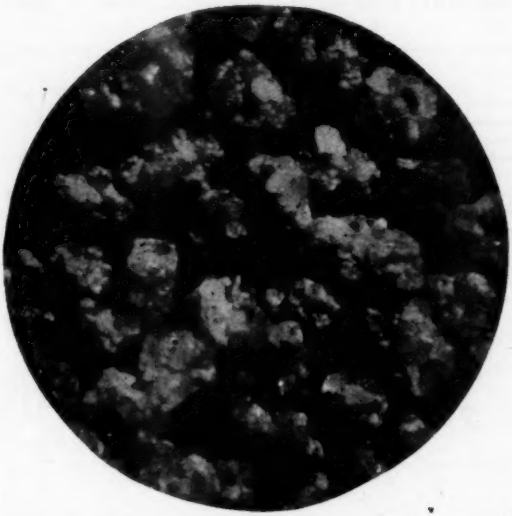

FIG. 1—ILLUSTRATING "COMPOUND GRAINS." THE A. F. A. COMMITTEE ON GRADING HAS RECOMMENDED THAT CERTAIN GRAIN AGGREGATES BE CALLED "COMPOUND GRAINS," SUCH A CLASS TO BE INCLUDED IN THE GRAIN SHAPE CLASSIFICATION.

the most uniform, and sand No. 4 the most widely distributed. All are of the same grain fineness, but their textures and their permeabilities differ: No. 1 is 50 per cent more open than No. 4, and has lower density and less green bond strength when tempered.

At present we have no way of expressing this grain distribution other than by giving all the sieve data or by expressing it graphically. Two methods that have been proposed for accomplishing this will be discussed briefly.

Tyler Method—The sieve analysis is put into cumulative form (see example below and chart of Fig. 2). It is then plotted graphically on a chart in which sieve openings in millimeters are laid out along one edge,

while percentages are laid out along the other. By interpolating on this chart, the sieve opening that will pass 10 per cent of the sample is found, also the sieve opening that will pass 60 per cent. This latter opening is divided by the former and the result is taken as the Distribution Coefficient. In formula form, this is:

$$\frac{\text{Mesh opening that passes 60\% of sample}}{\text{Mesh opening that passes 10\% of sample}} = \text{Distribution Coefficient.}$$

For example, take sieve analysis for sand No. 3, Table 1. Putting this into cumulative form we have the results shown in Table 2.

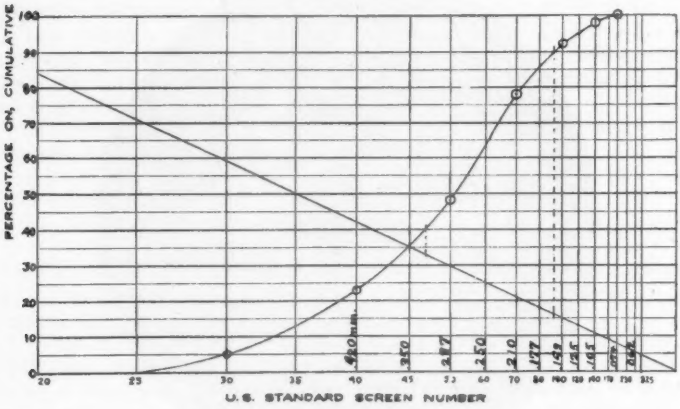

FIG. 2—SIEVE ANALYSIS OF SAND SAMPLE NO. 3 (TABLE 1) BY TYLER GRAPHIC METHOD. ANALYSIS AS FOLLOWS:

	Screen No.						
	30	40	50	70	100	140	200
Per cent on each screen	5	18	25	30	14	6	2
Per cent cumulative	5	23	48	78	92	98	100
A. F. A. grain fineness							50
Effective size							0.160
Uniformity coefficient							2.06

Plotting these data, we have the curve on the chart of Fig. 2. Interpolating for the opening passing 10 per cent, we have 0.160, and for the opening passing 60 per cent we have 0.330. Then the

$$\text{Distribution Coefficient} = \frac{0.330}{0.160} = 2.06$$

Calculative Method—For lack of a better name, the other proposed method is called the Calculative Method in contrast with the Tyler Method, which is more or less graphic. This method is described in

Table 1

SIEVE ANALYSES OF FOUR DIFFERENT SANDS.

	Analyses, per cent—			
	Sand No. 1	Sand No. 2	Sand No. 3	Sand No. 4
Fineness:				
On 20	0	0	0	0
30	0	0	5	23
40	0	7	18	19
50	0	12	25	17
70	100	71	30	15
100	0	8	14	12
140	0	2	6	8
200	0	0	2	5
270	0	0	0	1
—270	0	0	0	0
Grain fineness	50.0	50.0	50.0	50.0
Distribution coefficient—				
Tyler graphic	1.00	1.24	2.06	3.48
Calculative	1.00	.962	.852	.714
Permeability—				
Dry	127	111	95	85
Tempered	210	187	160	125
Density, dry, grams/100 cc	166	171	177	184
Green bond, tensile, ozs	1.25	1.41	1.55	1.75

NOTE: The moisture contents of the tempered samples were approximately the same, namely, 1.30 to 1.40 per cent.

Table 2

CUMULATIVE RESULTS OF SAND NO. 3 OF TABLE 1.

Mesh	Sand No. 3	Cumulative
On 6	0	0
12	0	0
20	0	0
30	5	5
40	18	23
50	25	48
70	30	78
100	14	92
140	6	98
200	2	100
270	0	100
—270	0	100

detail in Vol. 35 (1927), TRANSACTIONS A. F. A., pp. 189-91. In Table 3 it is applied to sieve analysis of sand No. 3, Table 1, in order to compare its operation with that of the Tyler Method. The grain fineness is calculated as usual.

A coarseness factor is calculated by a similar method, with this exception—instead of the regular multipliers, their reciprocals are used, or the fractions are divided by them instead of multiplied.

Table 1 shows both distribution coefficients for each sieve analysis and their relation to other physical properties.

The relative advantages of each of these systems for measuring grain distribution are being studied by the committee with view to recommending one of them for adoption as standard.

Table 3

CALCULATION OF COARSENESS FACTOR

	Fineness		Coarseness	
On 30 mesh	5 × 20 =	100	5 divided by 20 =	.250
40 mesh	18 × 30 =	540	18 divided by 30 =	.600
50 mesh	25 × 40 =	1000	25 divided by 40 =	.625
70 mesh	30 × 50 =	1500	30 divided by 50 =	.600
100 mesh	14 × 70 =	980	14 divided by 70 =	.200
140 mesh	6 × 100 =	600	6 divided by 100 =	.060
200 mesh	2 × 140 =	280	2 divided by 140 =	.014
	100	5000	100	2.349

$$\text{Grain fineness} = \frac{5000}{100} = 50.0 \qquad \text{Coarseness} = \frac{100}{2.349} = 42.6$$

$$\text{Grain distribution} = \frac{42.6}{50.0} = 0.852$$

Colloidal Properties

The committee recognizes the need for means to evaluate and grade clays. Not only have standard methods for testing clays not been developed as yet, but we seem to have no standard terms in which to describe them. The wide differences between finely-ground silica flour, fireclay, bonding clay and bentonite are readily apparent, but we need standard terms for describing and standard methods for measuring these differences. Information on this subject is gradually being accumulated, however, and the committee hopes soon to propose methods for grading clays in a practical and useful manner.

The question has been asked, "Why not just measure the bonding strength of a clay and be done with it?" In many cases such a test or such tests will serve and nothing further needs to be done.

Bonding strength, however, is only part of the story. Water absorption, plasticity and other properties, too, are very important in determining the value of a clay. Furthermore, bond tests are highly variable with moisture content, nature of water used in tempering, method of mixing, etc., so that every detail of such tests which may have a bearing on the test results must be standardized. The Grading Committee is cooperating with the Test Committee in efforts to provide satisfactory methods for evaluating the clays in molding sands as well as bonding clays themselves.

The chairman wishes to express his appreciation of the splendid cooperation of the members of the committee in carrying on this work.

Respectfully submitted,

A. A. GRUBB, *Chairman*,
Committee on Grading.

DISCUSSION

ORAL DISCUSSION

DR. H. RIES:* Mr. Grubb, do you think that the compound grains break up in the disintegration of the sand for the fineness test?

A. A. GRUBB:† No, they do not. There is a rather important point in this respect; it gives a false impression of the fineness of the sand. We had, in one case, a sand from Illinois that had a grain fineness of about 90. After it had been crushed with a wooden stick, the fineness figures went up something like 50 per cent. That is an exceptionally large difference, however.

DR. H. RIES: Is it your personal opinion that, in making a fineness test, any compound grains present should be broken up?

A. A. GRUBB: We find that in some cases we can break them up easily, but in other cases a mortar would be required. If we use a mortar, we would break up some of the primary grains, so I do not believe we should attempt to break up such aggregates.

DR. H. RIES: I believe they would not last very long in the heap if they could be crushed easily with a wooden stick.

*Cornell University, Ithaca, N. Y.
†Grubb & Marshall, Columbus, Ohio.

Report of Committee on Conservation and Reclamation

To the Members of the American Foundrymen's Association:

The Committee on Conservation and Reclamation has held no meeting since the convention in Chicago. It has endeavored, however, through its various members, to keep abreast of the activities in conservation and reclamation throughout the country.

This year the committee departed from a previous custom, which was to obtain general information from various foundries as to their progress in sand conservation, and has endeavored to obtain more detailed information as to the manner in which conservation and reclamation actually has been carried on. Pursuant, therefore, to this policy there was incorporated in the March, 1930, A.F.A. Transactions and Bulletin, page 22, the following notice:

> Data Desired on Effect of Bonding Agents
>
> "In connection with the report of the A. F. A. Committee on Reclamation and Conservation of Foundry Sands, the committee is desirous of securing authentic engineering data on the effects of adding bonding agents to foundry sand heaps. This report will be presented at the Cleveland meeting.
>
> "The types of bonding agents under consideration include clays, bentonites and heavily bonded natural sands. The data should show their effects on the properties of the molding sand and on castings produced, and should be obtained from actual commercial practice.
>
> "As this material must be approved by the committee before the Cleveland annual meeting, to be included in this year's report, it should be received at the office of the secretary of the A. F. A. not later than April 15."

As a consequence of this notice, and of the desire of many firms, both users and producers, to cooperate with the committee, a number of engineering reports were received, all of which are made a part of this report under Appendix A.

Data on Steel Casting Field

In line with the policy of the committee to put before its members information covering as much of the field as possible, the report given below covers in general the sand conservation and reclamation situation in the steel casting field:

> "The progress of molding sand reclamation for steel foundries continues. Quantitative data have been published which bring the fundamental considerations of reclamation into much more definite form and remove this matter further from the category of opinion.

"Some experimental information has been recorded which shows the temperatures to which the sand is subjected and speculates as to the quantity of sand exposed to the maximum temperatures. These speculations certainly suggest that the quantity of sand exposed in a given mold is comparatively small, and therefore the amount of good sand remaining is so great that a treatment for the removal of fragmented and fluxed grains is certain to leave a useful product.

"The information shows what it is in a used sand that must be removed before the continued use of the sand is advisable, and it emphasizes the necessity of a preparation of a used sand before the separation of the good from the bad. Practical experience over a long period of time in specific cases proves conclusively that the reclaimed sand does not suffer deterioration from continued use, except for the small quantity that fluxes with the metallic oxide and that suffers mechanical fragmentation.

"It is obvious from the published results that the value of reclamation is in proportion to the cost of new sand and the wasting charge. It is also evident that the amount of refuse from a reclamation operation (among other things) is dependent upon the amount of natural bond the new sand originally contained and the amount of binders used in the sand mixtures.

"On the whole, the past year has put into the hands of the steel foundrymen much more definite information than they have heretofore had, and should be most suggestive to those whose sand supply is far removed from their operations."

Data on Nonferrous Field

The following report covers the committee's attempt to obtain data in the nonferrous field:

Approximately eighty of the most prominent brass foundries were circularized, the addresses being obtained from *Penton's Foundry List*. A general classification of the results of our questionnaire is as follows:

Six letters returned. Our *Penton's Foundry List* was about three years old and these companies, no doubt, are no longer in existence.

Three letters of acknowledgment received, but gave no information.

Two letters received giving only sand producers' trade name of sand used.

Six letters giving data more or less in available form based on A. F. A. tests.

In view of the little response to the questionnaire—about 7½ per cent replied with any information—it may be assumed at present

the brass foundry trade either does not care to exchange data or has none to present in respect to the properties of molding sand. As there is but a small amount of data available in the reports received, the physical characteristics of the sands noted in Table 1 should not be considered in any other light than a general indication of the types of sand employed in the nonferrous field.

Table 1

SANDS EMPLOYED IN NONFERROUS FIELD

New Sand as Received.

	Grain fineness.	Clay.	Bond.	Perm.
For light work.....	200-245	7-20	5-8	8-12
For medium work.....	140-170	9-20		

Sand in Heaps.

	Grain fineness.	Clay.	Bond.	Perm.	Moisture.
Light and medium work ...	180-200	9-12	2-6	9-20	5-7

In conclusion, the committee can only go on record to the effect that (1) conservation and reclamation of molding sand, at least so far as the gray iron, malleable and steel-casting field is concerned, continues to progress; and that (2) through the application of intelligent methods of control and proper selection of material, there are even further possibilities toward that end of quality castings produced more economically.

Respectfully submitted,

R. F. HARRINGTON, *Chairman*,
Committee on Conservation and Reclamation.

APPENDIX

SAND CONSERVATION AND RECLAMATION—REPORTS ON PLANT PRACTICE

PLANT "A":*

This gray iron foundry pours approximately 300 tons of miscellaneous gray-iron castings per day. The product is used in agricultural tractors. The castings are made from approximately 270 active patterns and vary widely in size and weight, from light bench work, snap and floor work of medium weight, to large tractor side frames weighing 800 lbs. each. A few of the variety of castings made are as follows:

Pistons
Large flywheels
Side frames
Cases
Cylinders
Cylinder heads
Sprockets
Pulleys
Housings
Wheels

*Data obtained through Illinois Clay Products Co., Chicago.

The sand handling is classified as semi-manual. Heap sand for facings is handled with a tractor to the muller, which is located at the storage bins for No. 2 Ottawa silica, fireclay and sea coal. The discharge of the mixer opens into a bucket conveyor which elevates the facing on a rotating screen, through which it falls into dump tanks that are hauled to the molding floors by lift trucks.

The shakeout heap sand, new silica sand (washed and dried), and fireclay flour are trucked to the foundry mixing department, where the many facing mixtures and heap-sand additions are mulled. After mulling, the sand is trucked back to the several floors.

The sand used for the heavier work is entirely synthetic. The molds for a casting weighing 800 lbs. are made with a sandslinger and no facing sand is used. The heap is itself a facing mixture.

The regular heap addition is as follows:

10 parts silica sand
3 parts fireclay flour
4 parts sea coal

This mixture, when mulled with 5 per cent moisture, is added in sufficient quantity to maintain volume, permeability and strength at specified figures, the established standards being as follows:

Permeability.	Shear strength.	Per cent moisture.
70-80	1.5-1.8	5.0

The synthetic addition is spread over the heap each night and is cut in with a sand cutter arrangement on the tractor type of slinger. The remaining sandslinger floors use facing mixtures suitable for the size and type of casting made, but all have the same synthetic sand addition, namely:

10 parts silica sand
3 parts fireclay flour
1 part sea coal

This mix is known as the standard synthetic mix.

A slinger heap, in which castings of approximately 125 lbs. average weight are made, is maintained through the addition of the standard synthetic mix.

The facing mix is as follows:

32 parts heap sand
4 parts sea coal

The standards for this floor are as follows:

	Permeability.	Shear strength.	Per cent moisture.
Facing sand	60-70	1.5-1.7	5.0
Heap sand	60-70	1.3-1.5	5.0

A sandslinger, making molds for castings with average weight of

100 to 150 lbs., is maintained with the standard synthetic mixture. The facing sand is as follows:

30 parts heap sand
2 parts silica sand
4 parts sea coal
1 part fireclay flour

The standards required for this floor are as follows:

	Permeability.	Shear strength.	Per cent moisture.
Facing sand	70-80	1.7	5.0
Heap sand	70-80	1.3-1.5	5.0

The facing mixture and standards for another sandslinger making molds for castings averaging 50 lbs. per mold are shown in Table 2.

Table 2

SAND SPECIFICATIONS FOR CASTINGS AVERAGING 50 LBS.

Facing Mixture

32 parts heap sand
2 parts silica sand
3 parts sea coal
1 part fireclay flour

Standards

	Permeability.	Shear strength.	Per cent moisture.
Facing sand	67-79	1.6	5.0
Heap sand	67-72	1.5	5.0

Other smaller castings are made on side floors without the use of sandslingers. The average standards for these floors are as follows:

Permeability.	Shear strength.	Per cent moisture.
40-60	1.2-1.5	5.0-6.0

A mixture of two parts of heap sand and one part fireclay flour is milled and added to heaps to maintain above standards. Occasional additions of new sand are made to supply volume, while the core-sand residual to shakeout is present in sufficient quantity to maintain permeability.

At present, due to lack of adequate facilities for removing fines, no gangway sand is reclaimed. It is interesting to note that, in the practice followed at this plant, a 25 per cent reduction in the amount of fireclay flour necessary to maintain the strength at standards is accomplished by mulling the fireclay with heap sand, spreading the addition on the heap, cutting dry and then recutting and tempering.

Realizing the importance of control tests, all batches of facing, heap

additions and synthetic-sand additions are tested. Each heap is tested every day, sandslinger heaps four times, and side floors once. Further tests are made at night on the slinger heaps.

Permeability, shear strength and per cent moisture are the values checked on apparatus approved by the American Foundrymen's Association. The results of the tests are recorded on standard forms and filed in a permanent record available to all foremen.

In this plant, the effect of the general sand practice has been toward an appreciable decrease in scrap loss and improvement in surface of the castings. Cleaning costs are lower and the supervision necessary to the sand-control program has resulted in a freer and more positive understanding of the various molding problems encountered.

PLANT "B":*

Plant "B," a gray iron foundry which is pouring approximately 100 tons of castings per day for washing machines, is a unique plant in many ways. The scope of this paper prohibits a treatment of the integration carried on in the foundry as well as in the cooperating departments.

Suffice it to say that the human element is practically eliminated and mechanization carried to the final degree. The castings vary in size from a few ounces to 20 lbs. and include such pieces as gears, gear blanks, gear casings, wringer frames and legs. All castings are machine molded and held in metal flasks.

The sand-handling system is one of the many modern features in the plant. A parent hopper holding 220 tons of sand feeds onto a conveyor belt at the bottom, up an elevator to a tempering belt. The sand proceeds along the tempering belt through a revivifier onto another main belt, where a perpetual moisture test is made by means of an electrical device suspended over the belt into the sand. The operator for the tempering belt reads the moisture content on a meter at his elbow and records the readings every 15 minutes.

The volume of water added is varied to keep the moisture at the predetermined value. After passing the moisture recorder, the sand is carried by the cross belts to small hoppers at each molding machine. There are two molders to a hopper and 36 hoppers.

The molds are put on circular conveyors and poured. At a point in the circle the molds are dumped onto a shakeout conveyor, which carries the sand and casting to a revolving screen which allows the sand to pass through, and dumps the casting, sprues, etc., onto another belt conveyor, where they are pushed into buckets for tumbling.

The sand passes through the screen onto a belt and over a magnetic pulley which removes all shot iron, etc. Just before the sand reaches the magnetic pulley a hopper arrangement with a hole allowing a predetermined flow, makes the fireclay flour addition. Passing the pulley, the bonded sand goes up another elevator back to the main storage tank.

Three complete cycles of sand are made per day, and practically all sand is reclaimed, so much core sand being reclaimed that 3 to 4 tons

*Data obtained through Illinois Clay Products Co., Chicago.

per day of aluminum sand (permeability 10 to 12), must be added to insure smooth surface of castings.

No facing sand is used, the heap sand having a percentage of sea-coal facing. The amount of bond added is determined by the standards of permeability and strength, with the desired moisture.

Every 15 minutes tests of permeability, compression strength and per cent of moisture are made and recorded. This information is permanently filed and available to foremen at all times.

There is one sand with the following specifications for all castings, namely:

Permeability.	Compression strength.	Per cent moisture.
18	2.0-2.2	8.0

To maintain this strength, about 1,200 lbs. of fireclay flour are used per day for 240 tons of sand, with three casts per day taken from the sand. Fireclay flour is mixed with dry shakeout sand in equal parts and added as explained above. This is done to eliminate clay balls and to prevent the clay from sticking to the belts. The addition consists of 5 lbs. of fireclay flour to 3 tons of sand; for service requirements this is sufficient to maintain the proper strength.

The small addition of fireclay is made possible by the type of casting. The sections are light and the service on the sand not particularly severe. The sand-handling system obtains the maximum value from the clay.

There is no waste sand in this shop. Any sand carted away is done so because of core-sand aluminum sand additions. The castings need practically no tumbling because of the system of handling, which knocks out the cores and most of the sand before reaching the tumbling barrel.

PLANT "C":*

This is a malleable iron plant capable of pouring 100 tons of castings per day. These range in size from a few ounces to 100 lbs., the majority of the work weighing one and five pounds. The product is used in agricultural machinery. A few of the pieces cast are as follows:

Chain links	Levers
Gears	Supports
Needles	Hangers
Sleeves	Connecting rods for small gas engines
Yokes	

Most of the work is squeezer and jolt-squeezer molding, there being very little floor or bench work. This plant is different from most malleable plants in that 90 per cent of the casting is done in heaps and with facings containing no sea coal.

The more difficult castings use a milled facing composed of heap and silica sand and fireclay flour. This helps to improve the cleaning

*Data obtained through Illinois Clay Products Co., Chicago.

qualities of the casting. If castings have a pitted surface, a small percentage of sea coal is added to the facing, and in all cases where this is done a smooth surface is the result.

The sand handling may be classified as semi-manual. The additions of refuse sand, fireclay flour, new sand and silica sand are trucked to the muller, mulled and trucked back to the several floors. Refuse sand is sand adhering to the castings. No gangway sweepings are used, it being found that their continued use lowered the permeabilities to a dangerous point.

This plant requires 100 loads of sand per day, each weighing 400

Table 3

SAND STANDARDS FOR VARIOUS KINDS OF WORK

For Very Light Work

Permeability.	Shear strength.	Per cent moisture.
8-13	1.1-1.3	5.0-7.0

For Average Work

(Castings up to 8 lbs.)

Permeability.	Shear strength.	Per cent moisture.
18-30	1.0-1.2	6.0-8.5

For Heavy Castings

(Including floor molding.)

Permeability.	Shear strength.	Per cent moisture.
30-45	0.9-1.1	6.0-8.5

lbs., added to maintain volume and strength at specified values. The mix of additions to maintain volume is as follows:

12 parts refuse sand
2 parts fireclay flour
2 parts new sand (A. F. A. No. 3F)
1 part No. 1 silica sand

The test values of this mix are as follows:

Permeability.	Shear strength.	Per cent moisture.
25-35	1.2-1.4	6.5

Of course, the additions vary to suit the heap and type of casting made in the heap, and the additions are not arbitrary but are varied to meet these conditions.

For additions where excess core sand has weakened the heap, the following mix is added in the correct proportions:

12 parts refuse sand
5 parts fireclay flour

Just enough moisture is added to moisten the mix (approximately 2 per cent), and then after mulling it is spread on the heap.

The general division of standards in this plant may come under three classifications, as shown in Table 3.

It is fitting to mention here the system employed in this plant to make the additions to the various heaps. Every heap in the shop is tested for permeability, shear strength and moisture, on apparatus approved by the A. F. A. committee on sand control, and permanent records are kept.

With almost no exceptions, orders for additions to sand heaps, the type and amount of addition, emanate from the laboratory. These are in the form of written slips, given to the molder, who in turn gives them to the "sand man," who is paid according to the slips he presents to the Timekeeping Department. In this way very few extra additions are made and all additions supposed to be made are assured because the "sand man" will not be paid except for slips presented.

In this plant, as in others using fireclay flour for rebonding sand, a distinct improvement has resulted in supervision and surface of castings, with the resultant lowering of scrap loss and cleaning costs.

PLANT "D":*

This is a malleable iron company with a capacity of from 200 to 400 tons of automotive malleable-iron castings per day. More than 200 different castings are made, varying in weight from 2 ounces to 50 lbs. A few of the castings made are as follows:

Carriers	Brake pedals
Differential housings	Hubs
Steering-gear housings	Spark levers
Gear cases	Gas levers
Clutch pedals	Rim lugs

The sand handling is strictly mechanical, from the storage bins to the shakeout. Waste sand for reclamation is stored with fireclay flour, new molding sand, sharp sand, etc., in six 12½-ton hoppers. Various ingredients of the sand and additions are carried from these hoppers to mullers in measured quantities, by conveyor belts.

Facing mixtures are milled for six minutes, with the desired amount of moisture, and reclaimed sand mixes for additions are milled four minutes, dry. The discharge belt from the mixers carries the prepared sand to bucket elevators, which discharge to a revolving screen with ¾-in. mesh openings, which in turn discharges to an aerator. Facing mixtures are trucked to the points needed, and the additions are stored in bins of 12½-ton capacity.

There are three complete sand-handling units in operation at this plant, one of an older type, "A"; the other two, "B" and "C," being identical in arrangement and in general use.

"A" unit handles large castings. The flasks are shaken out over

*Data obtained through Illinois Clay Products Co., Chicago.

vibrating screens with ¾-in. openings. Through the floor grate over a cross belt carrying the shakeout sand, is added the following mixture:

45 per cent old sand
25 per cent fireclay flour
15 per cent molding sand (A. F. A. 70)
15 per cent sea coal

This mixture is added in sufficient quantity to maintain the bond strength at the proper level. An average of about one ton of the mixture is added for every 18 tons of iron handled. A small amount of water is sprayed on the belt, which passes over a magnetic pulley, and a bucket elevator then carries the sand to a revolving screen (½-in. mesh).

A tempering belt, on which the moisture is brought to about 4 per cent, carries the sand to a 50-ton storage bin, from which it is fed by a reciprocating discharge grate to a final tempering belt where the moisture is brought to approximately five per cent, the elevator and distributing belt then handling the sand to the flight conveyor and to 30 molders' hoppers (10 hoppers, 1000 lbs. capacity, to each flight).

Approximately 75 tons of sand are used in the unit, and this amount is turned over about ten times daily. The standards maintained are as follows:

Permeability.	Shear strength.	Per cent moisture.
70	1.4	5.3

"B" conveyor handles smaller castings, although the castings are of fairly heavy section. The shakeout arrangements are the same as on "A" unit, the sand being fed from the screens to a pusher-type trough conveyor, which discharges to a magnetic separator belt and a revolving screen with ½ by ¾ in. opening. After the screening, a small amount of water is added and the sand passed through a pug mill of the paddle type to a 100-ton storage bin. The discharge from this bin is by a revolving table, following which this mixture is added:

75 per cent old sand
19 per cent fireclay flour
5.1 per cent sea coal

The moisture is brought to the proper point, and the sand from a squirrel-cage-type revivifier passes through a "Y" pipe to two flight conveyors, each flight consisting of 20 hoppers of approximately 2700 lbs. capacity. About 160 tons of sand are contained in the unit, and it is used at the rate of about 75 to 100 tons per hour. The reclaimed sand addition is added at about the same rate as that on "A" unit.

"C" unit is practically the same as "B" in operation, the only change being that the reclaimed sand addition is added at the pug mill. The castings on "C" unit are of somewhat heavier section, and the sand burns out more rapidly. For this reason the ratio is about one ton of sand addition to 10 tons of iron handled.

Standards for "B" and "C" units are as follows:

Permeability.	Shear strength.	Per cent moisture.
70	1.5	5.5

Tests for strength, permeability and moisture are made at half-hour intervals on all units. The most important factor in control is moisture, and the operators responsible for moisture additions are paid on a sliding-scale hourly basis, the rate being determined by the per cent of variation from the moisture standard. This practically assures proper tempering.

The temperature of the iron poured is between 2800 and 3000 degs. Fahr. Produced by the duplex system, this extremely hot metal imposes severe service on the sand. With the exception of the small amount added to the sand in "A" unit, no new molding sand is used. The new molding-sand addition is principally to give a gradation of grain size and smoother finish. Very little facing sand is used, only occasionally on special work, the heaps being practically facing sands in themselves.

PLANT "E":*

This large gray iron jobbing shop generally pours 70 to 90 tons of castings per day. Both the weight of castings and the class of work vary widely, there being only a few patterns which are run as routine work. The bulk of the output is die castings for automotive work, most of them weighing between 200 and 500 lbs.

The greater part of the tonnage of the shop goes to make heavy machinery bases and frames, which vary in weight from five to 18 tons. Other types of work will weigh from one pound to one ton. The majority of the production may be classified as follows:

Die castings
Cylinders
Machine bases
Furnace frames
Machine frames
Manifolds
Furnace grate bars

The sand handling in this plant may be classified as semi-manual. Fireclay flour is stored at the muller in a small bin, and heap sand, sharp sand and sea coal are wheeled in. The operator mixes these in the proper proportions on the floor next to the muller, cutting the mix over with a shovel. He then adds the mix to the muller, about 500 lbs. at a time, mulls and tempers it, and it is wheeled to the floors to be used as facing. There are no bond additions made to the heaps except through the facing.

On the lighter-work castings weighing a ton or less, the following facing mixture is used:

36 parts old heap sand
5 parts fireclay flour
3 parts sea coal
1 part sharp sand

*Data obtained through Illinois Clay Products Co., Chicago.

The usual analysis on this mixture is:

Permeability.	Green compression.	Green shear.	Dry compression.	Per cent moisture.
30-50	10-15	2.5-3.5	45-55	4.5-6.0

For the heavier work, the following facing is used:

36 parts old heap sand
5 parts fireclay flour
7 parts sea coal
10 parts sharp sand

Analysis on this mix runs as follows:

Permeability.	Green compression.	Green shear.	Dry compression.	Per cent moisture.
60-80	13-15	3.0-4.0	45-55	5.0-6.5

Some of the very small work in this shop is done on squeezers; the remainder is all floor work, with some air rammers being used for the very large jobs. The amount of sand used is approximately one ton of sand to every 8½ tons of iron poured.

There has been a material reduction shown in costs since the installation of a sand-reclamation program. Material costs have been reduced 30 per cent and cleaning costs to a minimum, with a resultant improvement in surface of castings.

PLANT "F":*

This gray iron foundry has an output of approximately 180 tons of castings per day. These are all small automobile parts, ranging in weight from ½ lb. to 20 lbs. The majority of the work falls under the following classification:

Exhaust and intake manifolds
Brake parts
Clutch covers
Carburetor bodies
Tappets

Sand handling may be classified as semi-manual. There are a few floors, but 90 per cent of the work is done on two units of the "merry-go-round" type. Molds are poured on one side of the unit; fireclay flour is added on top of poured mold and castings are shaken out on opposite side, the shakeout being manual.

Sand from the shakeout drops to a conveyor belt leading to the center of the unit. It is tempered on the belt, and is dropped into a sand cutter, which throws it into a large wooden storage bin. The bin has openings at various points in the bottom and the sand comes out of these, by gravity, onto the floor. It is shoveled from there to the molds.

*Data obtained through Illinois Clay Products Co., Chicago.

Facing is used for all drags and on the gates in the cope. The facing is made by wheeling heap sand to a muller and adding fireclay flour and sea coal in the required proportions.

There is no standard for the addition of fireclay flour to the heaps; the foreman is constantly watching the sand and strengthens it as necessary. The addition will average one part fireclay flour to 17 parts old sand. Enough core sand is left in the heaps to maintain volume and permeability at the required values. The remainder of the cores are shaken out in tumbling, and are carried off as mill room waste.

Table 4

FACING MIXTURE AND SAND ANALYSIS IN ONE PLANT

Facing Mixture

20 parts heap sand
1 part fireclay flour
1 part sea coal

Facing Analysis

Permeability.	Green compression.	Per cent moisture.
35-45	3.5-4.0	6.0-7.0

Heap Sand Analysis

Permeability.	Green compression.	Per cent moisture.
60-70	5.0-5.5	6.5-7.5

Under present conditions the plant is running a total foundry loss of from 4 to 8 per cent, whereas their old practice gave them consistent losses of 17 to 20 per cent. This is not necessarily due to the use of a bonding agent; the general improvement in sand conditions, supervision and equipment brought about by attention to any one of these items means an improvement in all.

It is reported that there has been a marked improvement in appearance and surface of castings. The material and labor costs connected with the sand only have been cut almost in half, and it is generally felt that the rebonding and reclamation of the sand has proved itself to be satisfactory, both in economy and quality of castings.

PLANT "G":*

This is a plant which operates a gray iron and malleable foundry producing pipe fittings, gate valves, conduit fittings and castings. The average daily tonnage of gray iron melted is 28, and of malleable, 42.

The amount of sand reclaimed in gray iron daily is 11 tons; in malleable, 14 tons. For use on heavy work, the coarsest burned silica

*Submitted by Douglas M. Storie, Superintendent, Fittings Limited, Oshawa, Ontario, Canada.

sand that can be obtained from the milling room is used as facing and mixed as follows:

95 per cent burnt coarse sand (from inside of castings)
4 per cent clay bond
1 per cent sea coal

This sand peels from castings almost without cleaning. The shear strength is about 1.6 lbs. per sq. in., and permeability, 48 to 60. No trouble is experienced with blows, although sand is rammed hard.

For use on medium work, sand from the milling room, which comes off the outside of castings, is mixed as follwcs:

50 per cent mill room sand
48 per cent heap sand
1½ per cent clay bond
½ per cent sea coal

This mixture has a strength of 1.2 or 1.3 lbs. per sq. in., with a permeability of 38 to 40, and cleans from castings with a little better than half the milling required to clean castings made in ordinary molding sand. The above figures are strictly adhered to, as it is found that a variation in any way causes difficulties.

For example, it has been found that if strength is greater than 1.2 or 1.3, and moisture content is about 4 per cent, the presence of the excess clay will prevent the sand from ramming tight to pattern, causing pebbly castings; also, there is a tendency for the clay to stick to the pattern. On the other hand, if the strength is allowed to run below the above figure, the absence of sufficient clay will leave numerous grains of sand loose, which will naturally float with the iron to the surface of castings, making innumerable pin holes in the skin and spoiling them for plating or galvanizing.

There are a certain number of fittings of odd sizes which are split patterns, made with a green-sand core, and which had given a great deal of trouble with blows and cuts until the use of clay for reclaiming purposes was begun. It was found necessary to have a sand that can be rammed hard without blowing, and also to have it strong enough to prevent any cuts or washes. For this purpose core ends from the foundry are collected and ground up, and the sand is given a thorough burning in an annealing kiln. This sand is mixed as follows:

97 per cent burnt core ends
2 per cent clay bond
1 per cent sea coal

This mixture has proven to be very satisfactory, and although it is an added expense to burn the core ends in the annealing kiln, it is felt that, in view of reduction in losses, it is well worth while.

During the course of this plant's experience in reclaiming sand, one of the worst obstacles encountered was that of the facing sand heating up and drying out in the storage bins, and at times in the molds. This naturally caused heavy losses. For some time the plant was at a loss

to explain or overcome this situation, and in fact is not entirely master of it yet.

After a great deal of experimenting they came to the conclusion that the sand they were using from the milling room at times contained core sand from castings, which were not heavy enough to entirely burn out all the binder, and that as soon as it was put through the muller and came in contact with moisture, it developed a heating action. The only recourse open was to mill the light castings having cores separately, and to use the sand in the core room. In spite of this precaution they continue, at intervals, to be troubled with this condition of heating of the facing sand.

One great advantage derived from using clay bond is the lifting of deep, difficult pockets without the aid of gaggers or "soldiers." In a great many cases, by increasing the bond in sand slightly and reducing the moisture content accordingly, it is possible to speed up production on jobs which have previously been slow owing to the use of gaggers or "soldiers."

It has been found that it is not practical to try and make very light work with medium-grade facing sand, as too much ramming is required to close the sand tightly enough to leave a perfectly smooth finish. In this case a No. 1 Albany molding sand is used mixed with the medium-grade facing to suit the requirements of the castings being made.

Sand condition is controlled by the man mixing the facing, and by the sand tester. All heaps are tested every day, and the facing every day; the results are marked on a charted layout of the foundries. When a bucket of sand is taken from a floor to be made into facing, the condition is noted by looking at the chart, and strength and permeability are increased or decreased so as to maintain the standard, which has been set up to suit this plant's own conditions.

Sand is all put through a muller and each batch is mixed for five minutes. In fact, the proportion of clay used is governed by the length of time the sand is mulled. If more time was allowed, the percentage of clay could be cut down accordingly.

For both foundries, 575 tons of reclaimed or reconditioned sand are used per month, and only 98 tons of new molding sand.

Reclaimed sand in the core rooms is also an economical practice. Raw core ends are saved and ground in a muller, and used in the following mixture:

74 per cent ground core ends
24 per cent silica sand (golden)
2 per cent linseed oil

When it is realized that up until a short time ago these core ends were thrown out in the yard, it appears to be a real saving to reclaim them.

Sand from the milling room which cannot be used in foundry is used in the core room with the following mixture:

27 per cent mill room sand
27 per cent No. 2 Albany molding sand
17 per cent fire sand
27 per cent Lake Michigan sand
1 per cent rosin
1 per cent glutèrine

In the first core mixture given, some variation is found in the green strength of the core, due to the variable percentage of binder in the raw core ends, as there are many different mixtures used in the making of cores. This condition can be controlled by testing the sand regularly.

PLANT "H":*

The foundry of this plant, producing automotive castings for more than four years, has used a synthetic sand for the cast iron molds. Approximately 100 tons of iron are poured per day into cylinder blocks, heads, manifolds, flywheels, transmission cases and such miscellaneous castings that go to make up the motor.

All of the above, with the exception of a few small miscellaneous parts, are poured into green-sand molds. The latter are permanent-mold cast. All molds are made by machine and are held in steel flasks. The weights of the castings as poured vary from 7 to 275 lbs.

One type of molding sand is used for all castings. In all except two cases the same sand is used for facing and backing sand. The sand is entirely made up of used core sand, to which is added a mixture of clay bond and sea coal. Sand is riddled on the pattern as a facing and the backing sand added directly from the hopper. There are about 120 tons of sand in the system and about 240 tons of sand are used per day, so that the sand in the system is used about twice each day.

The sand-handling equipment is a system consisting of two hoppers for the untreated sand, each holding about 60 tons, and one hopper of about the same capacity for the treated sand, from which it is delivered to the hoppers located over the molding machines. The untreated sand from the hoppers is carried by bucket conveyors from the bottom of the hopper up to a horizontal belt conveyor.

The clay bond and sea coal are elevated from a hopper below the floor to a small adjustable feed hopper, located over this belt, to be added to the sand. The belt carries the sand and bond to a rod mill, which is operating continuously. Water is added to the sand just as it enters the rod mill, in a stream that is controlled by the operator.

The sand passes through the mill in about one minute and is discharged into an elevator which carries it up to the treated sand hopper. At the point where the sand leaves the conveyor a cross belt is located, upon which the sand would fall unless deflected into the hopper. This cross belt carries the sand, when needed, to another horizontal conveyor which consists of a large chain-driven series of cross plates that drag

*Submitted by J. E. Coon, Foundry Metallurgist, Packard Motor Car Co., Detroit.

or push the sand over steel plates, through which openings are provided over each of the 24 hoppers fed by this conveyor.

In this way the first hopper is filled before the second, and so on, until each hopper is full and the sand passes over them. At the end of the conveyor a spillway is provided for any surplus sand carried beyond the last hopper. A chute carries this sand to the belt below the floor that returns all sand to the system.

Four independent mold conveyors of different size are fed by this one sand conveyor. A fifth, located on the opposite side of the large hoppers, is fed by sand in the treated sand hopper. The sand is elevated from the bottom of the hopper to a belt which empties it onto a conveyor —similar to the one just described—which runs perpendicular to the belt and feeds four hoppers located over molding machines; a fifth, at the end of the conveyor, acts as a spillway from which sand may be drawn off and disposed of.

The castings from the four mold conveyors first mentioned are shaken out at two points over vibrating grizzlies. The castings are passed onto a conveyor to be sorted, and the sand and some of the cores pass through the grizzly and are conveyed to the belt which returns the sand to the system. The sand from the fifth conveyor is handled in a like manner from the shakeout located at that conveyor.

The sand in returning is passed over magnetic separators which remove all iron particles. It is then elevated to revolving cylindrical screens located over each of the hoppers for untreated sand. The sand passing through the meshes of the screen falls into the hopper, while the pieces of cores which pass out the end of the cylinder are carried by chute to trailers. These core pieces are then transferred to the core sand reclamation system.

An exhaust system is connected with the sand equipment to remove all fine dust from the untreated sand.

Daily samples are taken from the molding-machine hoppers at two different points for laboratory tests, and the following properties are maintained:

Per cent Moisture.	Permeability.	Doty bar cohesiveness.	Per cent bond.	Per cent sea coal.
4.5-5.0	60	160 min.	14	6-7

Sand data are plotted on charts in the foundry where they are available to the foremen. From two to three tons of clay bond are added each day, and about an equal amount of sand is spilled, or removed from the system. It is necessary to add about one-half ton of sea coal per day to keep the proper amount in the system.

Aluminum Sand

Sand-handling equipment has been used in the aluminum foundry for about a year and a half. The system contains about 75 tons of sand. About 270 tons of sand are used in a day, so that the sand in the system is used about four times each day.

This system handles sand for the crankcase, oil pan and toeboard,

all of which are machine-made molds. The smaller miscellaneous parts are made in bench molds from heap sand. About 60,000 lbs. of aluminum are poured per day. The castings vary in weight from 20 lbs. to 175 lbs. on the machine molds, or to 2¾ lbs. on the bench-mold castings.

The sand used is a finely crushed rock which is treated as a regular molding sand. The sand is mulled and tempered in a mill which is running continuously.

A batch of sand, after being mulled for two minutes, is deposited on a belt which carries it to an aerator. After passing through the aerator the sand drops onto an inclined belt which, after reaching the proper altitude, travels horizontally over six hoppers located over molding machines of one of the two mold conveyors. The sand is fed into the hoppers by means of a scraper which can be lowered onto the belt. A similar scraper deflects the sand flow from this belt to another belt running below and perpendicular to it.

The sand is again removed from this second belt to a third which runs parallel to the first and feeds the six hoppers of the second mold conveyor. The second belt also carries sand to a hopper, located at its end, for a green-sand core machine. Chutes are provided at the ends of the other two belts to carry the surplus sand down to the belts returning the sand to the system.

The castings are shaken out over stationary grizzlies which allow the sand to pass through on the return belt. The belt carrying the sand back makes contact with a magnetic pulley over which a belt is traveling that carries all chills, nails, etc., up to a sorting bench. The sand is elevated to a large storage hopper over which a vibrating inclined screen is located to remove pieces of cores and aluminum which have passed through the shakeout. The sand falls through the screen into a hopper which is located directly over the mill.

About one ton of new sand is added each day to provide for the amount lost to the system. If the sand is weak and the system is full, clay bond is added instead of the new sand.

Daily samples are taken from each of the mold conveyors and the properties maintained are as follows:

Per cent moisture.	Permeability.	Doty bar cohesiveness.
4.0-4.5	40	180

Core Sand Reclamation

The core-sand reclamation equipment has been in operation for the past six months. The installation consists of a jaw crusher set below the floor level, next to the shakeout of the crankcase.

All dry-sand cores that do not fall through the grizzly, and cores mentioned above from the iron foundry, together with scrap cores and sweepings from the core room, are fed into the crusher. The sand is then elevated to a magnetic separator, thence to a mill, to be ground.

A perforated plate on the floor of the mill allows the ground sand to fall through to a hopper. A by-pass allows the aluminum chips, etc., to discharge by opening the door of the mill.

The reclaimed sand is transferred to a bin in the core-mixing room, where it is used in all heavy cores in the ratio of one part new sand to one part reclaimed sand.

About 19 tons are reclaimed per day, which amounts to 32 per cent of all core sand used. This has also produced a saving of 145 quarts of dry binder and 140 quarts of linseed oil per day.

PLANT "J":*

Here is a company which operates two plants engaged in producing gray-iron castings for the automotive trade, consisting of gear blanks, pistons, housings, manifolds, cylinder heads and cylinder blocks. The weight of these castings varies from ¼ lb. to 350 lbs. each. All castings are machine molded and metal flask equipment is used on all production work.

When operating at capacity, the two plants melt 450 to 500 tons of metal daily, approximately 75 per cent of which is casting weight. Ninety per cent of all work is produced on roller conveyors. No power conveyors are used in this plant.

Four separate sand-handling systems supply sand to the molding conveyors. The sand-handling systems consist of a storage hopper, tempering belt, revivifier, distributing belt to molding-machine hoppers; then, from shakeout, the used sand is conveyed by belt to a revolving screen of ¾ in. mesh, thence over a magnetic pulley and back by bucket elevator and belts to storage hopper. Seven to eight complete cycles are made per 10-hour day.

Considerable sand is removed with the castings from the systems, and to replenish this sand in the system burnt core sand, which has been rebonded with ground fireclay or bentonite, is used.

When cores are removed from castings in the knockout room, the burnt cores fall on a conveyor belt and are elevated by bucket elevator to a screening system located on top of three large storage bins. This screening system consists of a series of bars to remove lumps which fall into the first bin. The burnt sand falling through the bars is conveyed over two magnetic pulleys and is then passed over a 14-mesh screen and stored in two bins of 50-ton capacity each.

The sand that passes through the 14-mesh screen is used for rebonding purposes. This sand is bone dry and is fed by gravity into a measuring bucket, where the required amount of bentonite or finely ground fireclay addition is made, elevated into a mill and mulled about five minutes with proper water addition. The mulled sand is conveyed into the foundry in the hopper truck and distributed to the various sand systems by dumping into the shakeout hoppers.

About 75 tons of this sand are used per day. This rebonded sand does not produce a satisfactory surface on the casting, so a facing is used on all castings requiring a good finish. A facing consisting of 65 per cent rebonded sand and 35 per cent fine new sand produces a much

*Submitted by F. Weiseham, Metallurgist, Ferro Machine & Foundry Co., Cleveland.

better finish on the casting. The constant addition of this rebonded sand maintains the bond in the system sand.

If for any reason it is necessary to increase the bond rapidly, bentonite additions are made on the belt before the sand enters the storage bin. This, however, is done only when a test shows the bond to be dangerously low. Tests on system sand are now made three times a day to indicate any change in bond or permeability.

With rebonded sand the tendency is for the permeability to increase. To decrease the permeability, addition of a fine molding sand is made to the system. Bond strength is adjusted by decrease or increase of bentonite or fireclay.

System sands are maintained near the following standards:

Permeability.	Shear, lbs. per sq. in.	Per cent moisture.
35-40	1.8-2.1	7

Facing sands contain a large percentage of new sand. They test as follows:

Permeability.	Shear, lbs. per sq. in.	Per cent moisture.
20	1.8-2.0	6

One ton of bentonite rebonds 18 tons of burnt sand; or 3½ tons of fireclay are used for this same purpose. Cost of rebonded sand is approximately $1.00 per ton less than the average cost of new sand per ton in Cleveland.

Considerable new sand is used in connection with the rebonded sand. Experience has shown that some new sand produces a better sand and better castings than rebonded sand used alone.

PLANT "K":*

This company operates a gray iron foundry which generally pours approximately 150 tons of castings per day for pumps, electric motors and generators, gasoline engines, windmills, lighting units, air compressors and diesel engines. Although all the castings made are consumed by the company, the foundry is in reality a jobbing shop, due to the great variety of the work made and the fact that only a few patterns are in steady production.

From 1200 to 1500 different patterns are scheduled per month and, of this number, from 250 to 350 are in the sand each day. The castings vary in weight from one ounce to 12 tons. Green sand is used for the general run of miscellaneous castings weighing up to 2500 lbs., and dry sand is used for large diesel-engine pistons and cylinders, bases, flywheels, etc.

There is no sand-handling system. All production green-sand castings are machine molded and the rest are rammed by hand. There are two sandslingers for dry-sand work—one of the locomotive type, the

*Submitted by C. B. Schureman, Foundry Metallurgist, Fairbanks Morse & Co., Beloit, Wis.

other of the tractor type. Production work not made with the slingers is jolted, and miscellaneous dry-sand work is hand rammed.

Facing sand is used for both green and dry-sand castings. Three kinds of green-sand facing are made—one for light castings, one for medium weight castings and one for heavy castings. These facings are made as shown in Table 5.

Table 5

GREEN-SAND FACINGS FOR LIGHT, MEDIUM AND HEAVY CASTINGS

	Heap sand, Per cent.	Bank sand, Per cent.	Lake sand, Per cent.	Crude silica, Per cent.	Bonding clay, Per cent.	Sea coal, Per cent.	Pitch, Per cent.
Light ...	61.0	30.0	....	....	4.5	4.0	0.5
Medium .	70.0	....	20.0	....	4.5	5.0	0.5
Heavy...	40.0	....	....	47.0	7.0	5.0	1.0

All percentages are by weight. The lake sand is from Pigeon Hill and the bonding clay is a well known clay bond. Specifications for these facings are as shown in Table 6.

The heaps are fairly well kept up by the facings. Occasionally, however, sand must be added to them, and a synthetic heap addition is made as follows:

48.0 per cent heap sand
42.0 per cent lake sand
10.0 per cent bonding clay

Table 6

SPECIFICATIONS FOR GREEN-SAND FACINGS

	Permeability.	Adams compression.	Per cent moisture.
Light	35-45	6.0- 7.0	5.5-6.0
Medium	45-55	7.0- 8.5	5.0-5.5
Heavy	55-70	8.5-10.5	5.0-5.5

No natural molding sand is used on any green-sand work. Synthetic sand has been used continuously for over two years with excellent results. Service on the sand is rather severe. Castings weighing several hundred pounds stand in the sand from mid-morning until they are shaken out by the night gang.

The dry-sand facing and the heap additions for the sandslingers are all synthetic. This is perhaps the only shop in the country using 100 per cent synthetic sand to make dry-sand castings weighing as much as 12 tons. It should be noted in passing that this shop is now operating 100 per cent on synthetic sand, both green and dry. The dry-sand mixtures cannot be given here, but the bonding agent is bentonite or a mixture of bentonite and a special clay bond.

At the present time the burnt core sand in the cleaning department is going to the dump. A reclamation system for this and for all refuse sand in the cleaning department is to be installed in the near future. The report for next year should show 100 per cent reclamation and 100 per cent synthetic sand.

PLANT "L":*

This plant's present method is as follows: Castings with cores are first brought into the cleaning room, where cores and sand are removed. Adjoining the cleaning room is the sand-separating room. Here the cores and lumps are broken up and shoveled onto a grating in the floor, through which they drop to a conveyor which in turn carries them to the sand-separating machine.

The separator is a vibrating machine driven by a 2-h.p. motor. For best results it has been found that the machine should run at approximately 1100 r.p.m. and should be tilted at an angle of 13 degrees with the horizontal.

The sand as brought from the conveyor enters at the top of the separator and falls onto a 3/32 in. mesh screen, which removes cinders, nails and other refuse. Anything finer than 3/32 in. falls through this screen onto a No. 20 screen (20 squares per in.) That which passes the No. 20 falls to a No. 40; that passing the 40, goes to a No. 80.

Due to the pitch of the machine (13 degrees), all sand not passing through the screens is conveyed by gravity to the front of the separator and into buckets; from there it is taken by truck to the sand storage bins to await mixing in the mixer.

The feature of the separating machine is that it gives five separations, three of which are of practical use; of the other two, one is taken from the top screen and one from the bottom of the machine (dust). This machine, as furnished by the manufacturer, contained but three screens, to which a fourth was added, as well as a dustproof sheet-iron covering.

Due to the vibration set up by the machine, the light dust tends to rise and is drawn off by a 6 in. suction line from the top of the machine and into a screen dust-arrester. The heavier dust, as previously stated, is taken from the bottom of the machine. By this method three grades of sand are obtained—Nos. 1, 2 and 3—which are used respectively for heavy, medium and light castings.

When a batch of a specific grade is required, it is placed in the muller as follows:

> No. 1 Grade—5 cu. ft. burnt core sand plus 5 cu. ft. old molding sand taken from heap where heavy castings are made plus 12 quarts clay bond.
>
> No. 2 Grade—5 cu. ft. burnt core sand plus 5 cu. ft. old molding sand taken from heap where medium castings are made plus 10 quarts clay bond.

*Submitted by James E. McHenry, Foundry Superintendent, Gleason Works, Rochester, N. Y.

No. 3 Grade—5 cu. ft. burnt core sand plus 5 cu. ft. old molding sand taken from heap where light castings are made plus 7 quarts clay bond.

The three grades are again ready for use after this mixing and are returned to the center, medium and squeezer floors.

DISCUSSION

ORAL DISCUSSION

MR. SHOEMAKER:* The reason I want to bring this before those of you who have conducted tests previously is because it is rather imperative that I get down to some basic information, and rather quickly, for the foundry involved. Having discovered, through reading literature and foundry articles, that certain acceptable standards are followed, I have found one particular thing to be true.

In the addition of a bentonite clay to our molding sand heaps, we seem to have increased the fineness of those heaps, or the silica content of those heaps, considerably. They seem to be excessive, ranging anywhere from 1.5 to around 20-25 per cent of what I would call excessive heaps.

Not having conducted the dye-adsorption test such as was suggested, has resulted in various molding-sand heaps varying in dry-bond strength, which we feel affects us anywhere from 25 to 90 plus on compression heating tests. That, again, has affected our castings in that we believe it has caused some shrinkage and surface checks, has caused these castings to become distorted and, in some cases, has caused a fusion (due to the fineness of the deposition of the fine ash) that has been detrimental to our product.

I present this situation with a view to securing some discussion as to what some of you have done in conducting tests previously and what might be considered an aid to overcoming the difficulty.

We are using about the same kind of sand, and although our tests are not as extensive as they possibly should be, we assumed the content of that particular sand to be uniform. Do any of the other foundries find that, over a period of time, an accumulation of fines passed by some process or other should be removed from the molding-sand heap from time to time? How is it accomplished?

R. F. HARRINGTON:† I think that I had better answer the question of Mr. Shoemaker personally, not as the chairman of the Committee on Conservation and Reclamation. It is our experience that, with the bentonite type of clay, we have rather increasing or higher permeability for a given amount of bentonite clay as compared to the other types of clay.

It seems to me the point is well taken on the dry-sand strength. We experience considerable variation in dry-sand strength on our heaps

*Millville Iron Co.

†Hunt-Spiller Mfg. Corp., Boston.

in which the clay bond is bentonite. We do not experience that difference to the same extent, I believe, in the heaps that are bonded with other types of clay. It is considerable of a problem with us as to just why that rather wide variation exists in dry-sand compression on some of those bentonite-bonded heaps.

I understand that the subject of variation in the dry-sand strength of bentonite types of clay is a matter of investigation with a number of different persons. I regret that from our own experience, in regard to this variation, we are not in a position to explain it. Certainly the dry-sand strength varies more widely than it should in the heap, while the green-sand compression, on the other hand, is relatively more uniform.

In our own practice it has not been of serious moment, but it is like a great many of those things—we aim to find out the reasons behind that variation, and as yet we have not been successful.

MR. SHOEMAKER: I have felt that possibly, with certain bentonites—as regards molding sand in connection with certain large patterns (for example, the banjo-axle type of pattern), with an addition of bentonite in the presence of a high fineness content of around 20 to 25 per cent on the pan—that the molding sand has a tendency to set up just like a piece of cement with the bentonite addition to it, and it seems to hold that casting out to where it does not come back to its normal pattern shape at all. It just seems to set right up and hold it there.

While we like bentonite for the surface—it does not give us a bad surface for the casting—on the other hand, it is detrimental in the way I have just mentioned.

R. F. HARRINGTON: In our own experience we have seen no evidence of fusion on the surface of castings which might be attributed to the use of bentonite types of clay. We have heard of instances where others have experienced the difficulty of excessively high dry-sand strength with possible trouble from cracked castings, or removal of the green-sand core portion in the cleaning department.

PAUL BECHTNER:* It is well known that the more fines there are in sand, the more moisture must be used to make it moldable; and that the more moisture used, the higher the dry strength becomes. All clays increase in dry strength with increase in moisture. The best green strength of bentonite, with a very coarse sand, is achieved with about 2 per cent moisture.

Mr. Shoemaker describes his sand as having a large percentage of fines, which means that he had to give it a great deal of moisture, which resulted in the high dry strength of the bentonite bond that gave him the trouble.

A man has informed me that his plant had installed a dust collector on an ordinary mixing machine—a rather new idea, which he said worked very well. They put a hood over the pan and a suction fan on the hood, and he said they cleared their sand of fines by that means. Of course, the sand has to be mulled dry while that is done.

*American Colloid Co., Chicago.

W. A. RENGERING:† I have never used bentonite because I could not differentiate between the bentonite and the molding sand clay in the heap. Also, in the course of experimentation I discovered that other mediums than one per cent caustic solution, such as common denatured or wood alcohol, would serve very well to deflocculate bentonite and clay and wash it off. I have used the clay determination method on bentonite samples and found it checked very well, and I have found considerable fine, gritty material in bentonite samples.

MEMBER: I believe I know the test mentioned. I did not use that test because it specifies grain alcohol, and I was afraid I could not get that. I did not know whether to use denatured or not, and whether I could get the same results with it.

R. F. HARRINGTON: Mr. Shoemaker has mentioned the extent to which the dry-bond strength has varied in his heap sands, and that he has not conducted the dye adsorption test as suggested. We have in our shop certain heaps using bentonite, and other heaps a certain type of clay as bond. Sometimes, through error, the incorrect bond will be employed and because of the distinctly different dye-adsorption characteristics of the two types of clay, we are able to pick up very promptly any discrepancies in the case of the two types of clay.

It is for this reason that we have stood by the dye adsorption test so faithfully. I believe Mr. Shoemaker has at his command, through the dye adsorption test, a ready means of better sand control.

W. A. RENGERING: However, I am not able to tell what per cent of the clay is ordinary molding-sand clay and what per cent is bentonite. I have learned from other sources that a little bit too much bentonite sometimes creates a considerable amount of scrap. I want to be able to have that factor absolutely under control.

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†Cincinnati Milling Machine Co., Cincinnati.

Reducing Materials-Handling Costs in Jobbing Foundries

By F. D. Campbell,* New York

Abstract

Observations and comparisons in use of mechanical handling equipment in gray iron, steel and nonferrous foundries, with means of reducing costs, are given. Proper planning and arrangement and installation of labor-saving devices have increased production over 100 per cent, with annual earnings on improvements estimated at 80 to 200 per cent. Average foundry's operating space is 40 per cent storage; mechanical equipment to utilize much of this space for operating alone is described. Hand molding and hand pouring are wasteful and expensive, hand pouring increasing accidents and labor turnover. Wage incentives are advocated, as necessary after basic labor reduction. Straight-line movement of all materials is primary need in foundry, based on flow chart of operation sequences, eliminating all possible cross or reversed traffic. Allocation of space for various operations should be determined by feed of incoming, not outgoing materials; turnover of floor space depends on cycle of heats. Paper discusses methods of sand handling and equipment, with cost comparisons; flask, pattern, mold and core handling and storage, and conveyors. Shakeout and cleaning offer great chance for cutting costs; by use of methods suggested, cleaning costs have been reduced 40 to 50 per cent. Great labor-saving element in core handling is in having unimpeded travel from core-sand mixers to all benches or machines, with conveyors for continuous production.

1. The foundry industry has ordinarily been divided into metal groups, but for any efforts toward solution of economic problems, divisions must be made with respect to types of business, production methods, quantities and types of product. The industry is rather well developed when matters of processes are

*Chief Engineer, Eastern Corporation, Graybar Bldg.

considered, but a great portion of it, as a whole, still is afflicted with high labor costs, when compared with other industries.

A Challenge to the Foundry

2. The great strides made in the manufacture of motor cars and other domestic necessities having cast component parts have been the means of rapid development in reducing labor costs in the types of foundries catering to those products. Such products lend themselves well to proper planning and straight lining of production, and the remarkable results achieved in low costs of production constitute not only a challenge to the rest of the foundry industry, but an indication of what it must be prepared to accomplish in the near future.

3. The broad fabric of the foundry industry caters to the general casting business. It consists of the jobbing foundry, the semi-production foundry, the production foundry (making miscellaneous castings, miscellaneous metals or alloys), air-furnace malleable-iron foundries, and periodic or seasonal products. This category will be referred to frequently as the average type of foundry.

4. Conceding satisfactory progress in processing, pattern practice, furnace practice, knowledge of molding sands, molding, cleaning and heat treating, what can the so-called average foundry do further, to better itself? What is the remaining point of attack to make further improvement, to secure better costs, more profits?

Labor Costs Must Be Reduced

5. Every foundryman knows the answer. It is in labor costs. Most foundrymen, we believe, can see an approaching change, a natural evolutionary trend born of economic necessity, but the question is, how can reduction in costs be effected? The element of labor costs presents a fertile field for investigation.

6. The foundry, primarily, makes a product that has a comparatively high proportion of labor cost in it. This is evidenced by the fact that, generally, of a dollar of net sales, direct, indirect labor and supervision represents over 45 per cent, with all materials at about half the labor item (ferrous plants); wherein, on the average, with other manufacturing industries, materials and labor approximately balance.

7. It is not our purpose to present any discussion of cost accounting methods, overheads, or what constitutes indirect

labor, our references being to labor—all labor of whatsoever description—which constitutes out-go in the form of payrolls. There are many and various methods of cost accounting in foundries, with no general agreement on merit, and this broad diversity of method probably accounts for a prevailing broad diversity of opinion regarding excessive items of costs, resulting in frequent journeys down blind alleys in search of cost-reduction possibilities.

Cost of Mass-Weight Movement

8. As evidence of what is probably the largest possibility in labor cost reduction, consider for a moment the mass weight that must be moved, carried, or lifted to produce castings—core sands, cores, molding sand, castings, flasks and other accessories, all in some continuously mobile state. Add to this great weight movement all the handling and rehandling of products in varying stages of process to deliver the finished article.

9. The grand total of weight movement to produce one ton of finished castings is variously from forty to one hundred and fifty tons. And many foundries still are moving a great amount of this aggregate weight by man-power.

10. Approximating one man at about one-tenth horsepower at 50 cents per hour, or $5.00 per horsepower-hour, man-power for mass weight movement is tremendously expensive by all accepted standards.

Necessity of Proper Layout of Foundry

11. When there is a necessity for greater production with no apparent extra available space in premises, enlargement of quarters may have little effect on cost reduction if the yield per square foot of floor space is not increased. Funds for new building may not be available, or, if they are, expenditure may be injudicious in the face of uncertain continuous demand for products.

12. Also there is the question of sufficiently rapid build-up of tonnage to prevent additional floor area becoming a heavy cost burden. In the matter of either requirement—that of reduction in cost of present or existing tonnage, or increased tonnage without corresponding increased cost or additional outlay—the problem is the same.

13. In surveys of many average foundries, one common prevalent condition was noted, that of illogical interior arrange-

ment of departments, equipment, storages, furnaces or cupolas, etc. This general condition results in waste motion, excessive labor, confusion, disorder, uneconomic use of floor space and equipment, delays, accidents, a higher semi-processed inventory, an extended manufacturing cycle and a lower turnover of both floor area and capital.

14. The average foundry's operating space is about 40 per cent storage, due to a conception that everything must be handy. Thus, that which should constitute active operating area exclusively is usually partly filled with inactive materials—flasks, boards, bands, etc.—some infrequently used. These storage areas are traps for debris and dirt, and cause rapid deterioration of equipment.

Molding Requirements

15. Molding, which is the vital part of the foundry, is generally restricted in operation, due to disorderly storages, unrelated flask-storage locations and, in the case of hand pouring, the use of much floor space as aisleways to reach all molds laid out on the floor in an immobile state.

16. When molds are of sufficient weight to require more than one man to lift from the machine, either others must leave their tasks to assist in carrying out sections or molds or cranes must be brought into action.

17. The accumulative time lost during the day, waiting for cranes in the handling of medium-sized work, is surprising in its magnitude. In connection with hand-made molds on the floor, molding operators are at a decided disadvantage in having to operate at many places over a considerable area, with much walking and carrying of sand and materials from available points to the particular spots where the molds are being made at the time.

18. If floor molders operate from large heap-sand floor storages, the work is carried on under the worst possible conditions of fatigue, inefficiency, hard labor and low production. And, when the day's work is laid out, it will be found that it actually occupies about 50 per cent of the floor space, because of molder's required operating space around each mold. Raking out the castings over a wide area will consume so much time as to reduce the effectiveness of floor area, due to the decreased production turnover of the floor. A further restriction is in the unorganized

method of flask movement in retiring unwanted sizes and replacing with required sizes, and the costly time element in delay to effect these changes.

Hand Pouring by Molders

19. Hand pouring by molding operators is costly compared with a trained pouring crew. Usually a realignment of labor about the plant will recruit sufficient labor for pouring when the balance of operations has been put on a proper basis. Responsibility may be vested in a good inspection crew for determining molding or pouring fault in defectives.

20. Another indictment of molder pouring is that, after a number of hours of molding, when the operator has done his best work and is nearer the fatigue point—lowest in physical energy and mental alertness—he is faced with the most difficult and hazardous task of the day.

21. Frequently the operator soon learns his physical limitations and will put up only the number of molds that he can possibly finish and pour off, thus fixing a low limit in earning for an allotted floor space. Studies made of this operation have indicated that it is not only highly wasteful, a breeder of accidents and burns, but also a direct cause of high labor turnover.

Shakeout and Cleaning

22. Shaking out over a wide floor area is costly, in labor involved to collect castings and to handle and condition sand, and in poor quality of sand conditioning and a resulting dust-laden atmosphere.

23. Cleaning operations in the ordinary way mean a conglomerate collection of product, movement from one point to another, without semblance of order or sequence. Generally, no matter how far behind the cleaning department may be, product is poured into it because of lack of storage space, resulting in greater confusion, increased inventory, longer time to get material through and a rising curve in ton-cleaning-costs in proportion to increased content results. With increased content of product, decreased contact time in processes follows.

24. On the average, the cleaning room is the notably unbalanced part of foundry operation, and it is the phase of production to which least attention has been devoted in any effort to correct obvious faults.

Wage Incentives

25. Wage incentives have been the hope of cost reduction, and have accomplished a great deal. That the greatest benefits have not thus far resulted from wage incentives alone is due to the fact that the application has been made to operations under conditions imposing great handicaps because of excessive basic labor. With the elimination of all possible labor, primarily, by whatever method, wage incentives may then be applied to the minimum labor requirement on reestablished rates.

FIG. 1—STORAGE AND POURING BAY. TWO-HOUR MOBILE STORAGE. HIGH-SPEED OVERHEAD POURING SYSTEM, WITH CENTRALIZED POURING POINT AND CENTRALIZED SHAKEOUT. MOLDING POINTS ARE ARRANGED ALONG EACH SIDE, WITH LATERAL DELIVERY TO STORAGE AREA. MISCELLANEOUS JOBBING WORK.

26. Wage incentive plans will improve existing conditions somewhat, but if applied after waste labor has been eliminated, such remuneration methods will provide the spur to effort and intelligent co-operation on the part of the operating personnel to produce the desired results. The point is that wage incentives are highly advocated, but should be introduced under proper auspices and conditions that will produce the greatest effectiveness.

27. It is believed that it will be evident, from a study of the foregoing, that the greatest single element in foundry opera-

tion that is presented as a possibility in lowered costs is in labor saving at every point where it can be accomplished. The greater proportion of labor reduction will be found in labor movement of materials.

Straight-Line Movement of Materials

28. The primary move is a plan of arrangement of operations based on a flow chart of sequences from the first operation through to the point of delivery of finished castings, eliminating all possible cross traffic or reverse movements. A straight line of movement is ideal and should be adhered to in principle if not in actuality. Each operation should be in relational location to preceding and succeeding ones.

Planning a Foundry Layout

29. In planning arrangement, the product must be considered. Melting equipment normally determines quantity output. The cycle of heats determines the turnover of floor space. Allocation of space or area for the various operations is dependent on the feed of all incoming materials and not on the outgo. This is vitally necessary to balance the production throughout.

30. For example, the molding department must absorb all materials, cores, patterns, flasks, sand, metal, and other accessories to produce rough castings in required quantity, variety and frequency.

31. The cleaning room must absorb rough castings fed from the molding department at the rate at which they are shaken out, and to clear them through at the same rate to shipping point. This principle of operation is vitally important if a fluid method of manufacture of castings is to be evolved.

Materials Handling a Science

32. The application of mechanical means of handling materials has become a science in many industries and is making some headway in the foundry; but the makers of miscellaneous castings have not embraced generally the full opportunities afforded by the use of handling equipment. The average foundry may employ profitably many varieties of materials-handling equipment, as may be evidenced by successful handling systems now in constant use in a number of foundries making a great variety of products.

Arrangement and Type of Equipment

33. In the materials-handling phase of the foundry, arrangement will vary chiefly with the product, whereas the selection of the handling medium will vary principally with the range of size of work.

34. For example, continuous pouring prescribes a certain arrangement; pouring off at the end of the day, another. Open-hearth and electric furnace practices each demand their individual plant layouts. The products of air furnaces also require definite arrangements in plan to meet the requirements of these practices, and the various nonferrous products necessitate individual treatment in each particular point.

Size of Product

35. The range of size of products, all the way from fractional pounds to tons, of necessity will determine suitable application in mechanics to effect the movement of materials economically. This phase of the engineering problem can be roughly divided into two sections, as follows:

First, the heavy-weight classification that requires a complement of substantial overhead cranes, hoists, etc., in combination with other floor systems of handling equipment or devices.

Second, the average and lighter-weight classification that may use types of fixed conveying equipment without recourse to much overhead handling other than for metal.

36. Generally, the so-called average foundries predominate in the lower-weight classification, although quite a number may be considered to be combinations of the two general classifications. In such cases it is merely a matter of classifying the various weights of work into segregated areas and applying the most economical means to the handling of each classification, as being quite distinct from each other. These references are being made to the movement of all materials, sands, cores, molds, metal and castings through all operations to completion.

SAND-HANDLING METHODS

37. The requirement for uniformly conditioned and economically handled sands is common to all foundries, whether they make large or small work. Handling methods and devices for this commodity are chiefly questions of extent in outlay to handle the capacity and required conditioning for the particular

FIG. 2—GROUPING OF MISCELLANEOUS MOLDS (SMALL ORDERS) FROM HAND-MOLDING FLOOR, READY FOR POURING.

grades of work. Sand handling plays a large part in foundry economy, in a number of ways.

38. Primarily, sand-handling and conditioning systems of present day design and method permit storage and conditioning units to be taken out of the operating areas, increasing the active floor area.

39. The distribution of sands to molding, when carried by overhead means, uses the ceiling, so to speak, which ordinarily has no value, being just the underside of a roof or upper floor. In this manner there is an increase of profit-yielding floor space.

40. Such mechanisms provide continuous or periodic distribution to all molding points, whether to molding machines or to hand floors, and an ability to uniformly condition the total required quantity of sand and—highly important—to provide a gravitation feed of sand to flasks, the benefit of which is unquestioned when considering that a molding operator will often shovel from 20 to 30 tons of sand daily.

Comparative Handling Costs

41. A molding requirement for 30 tons of sand hourly to be actually lifted for overhead distribution will require approximately five horsepower, with all fixed charges at, say, 10 cents per horsepower, or $4.50 per day of nine hours if run continuously. This more than equals the hand labor of ten men, putting it mildly.

42. This hand labor would earn approximately $6.00 per day, or a total of $60.00 per day for hand labor, compared with $4.50 for mechanical elevation. The balance of power costs and fixed charges for the entire sand-handling and conditioning system can be compared to all other labor incidental to the work of getting the sand off the floor and prepared for re-use, otherwise.

Methods to Suit Individual Conditions

43. Various methods of sand handling and conditioning may be employed to suit individual conditions. The system may be entirely centralized, from which central point all sands are distributed, or de-centralized in several smaller units, any one of which may be installed singly or progressively to suit any plan of gradual development by easy stages.

44. A centralized system may be started with a limited number of service points and added to or extended periodically to suit growth. Also, such systems may be designed for handling

and conditioning sands of varying kinds, and developed periodically and in varying grades to suit all types of work being made simultaneously.

Reduction in Flask Sizes

45. Another economy effected by overhead sand delivery is the requirement for a smaller range of flask sizes. A few inches in dimensions either way in flask size does not materially affect the time required to fill with sand from an overhead source, the result being that the average work can be accommodated in a certain restricted range of sizes.

46. Fewer general sizes of flasks will permit of sufficient quantities of each size to suit an economical turnover and reduce the number of changes in size daily in producing a broad miscellany in sizes or weights of castings. The smaller range of flask sizes will greatly facilitate the work of planning and pricing jobs and will also simplify accounting of piece rates and payrolls.

CORE HANDLING

47. The core department presents a wide range of handling methods and arrangement, the magnitude of which will be proportionate to production needs, size and variety of work.

48. For all purposes there should be an unimpeded lane of travel from core-sand mixers to all core benches or machines, and one that will not interfere with the making of cores or the movement of green or dried cores. Furthermore, the stages of operations should be arranged sequentially to prevent any cross currents of traffic.

49. Continuous core production may employ types of power conveyors or roller conveyors or combinations of both. The same applies in some cases to miscellaneous core production when large quantities are involved. Limited production at times profitably employs electric and hand-lift trucks, and pneumatic-tired hand trucks equipped with springs are very handy for speedy core delivery.

50. The great element of labor saving in core production is in elimination of movement of both operators and products by a practical plan establishing a certain order for all operations. Economies in core costs can be obtained in the same proportion as in the rest of the plant by simplification in plan, and frequently at initial costs which are proportionately less.

51. Suitable storage areas for plates, racks, and other

accessories should be made easily accessible but not to conflict with production in any way. A number of foundries have had splendid earnings in return for earnest and careful attention to the layout and design of their core departments.

MOLD STORAGE

52. In practically all foundries, with the exception of those continuously pouring, there must be more or less storage of molds to suit cycles of heats.

53. To reduce labor and still have requisite storage indicates that such storage must be mobile, with the same storage content ordinarily. In cases of increased number of heats or splitting to secure a greater floor turnover and employing a specific pouring crew, the storage space may be reduced in extent.

54. To provide a mobile storage of molds the roller conveyor has come into broad use for mold handling, enabling the molding operator to load his finished section or mold directly at the molding machine. Or, in the case of hand-made molds, it enables him to produce them on the conveyor with easy discharge or movement to storage areas, and in an arrangement, suitable for high-speed, economical pouring.

Minimum Friction in Conveyors

55. In order to move easily a great weight of product, the roller conveyor must provide a minimum of friction in operation. As the greater amount of molding is done in green sand, and demands are being made for closer specifications and finer detail and finish in the castings, the mold-carrying conveyors must be precisely made to obviate destructive vibration and to be continuously maintained in this condition. They must withstand metal spillage and sand and contain some effective method of bearing preservation by preventing entrance of abrasive matter and moisture to the bearing elements.

56. There have been many attempts to employ roller conveyors in mold handling, but without success, due to lack of attention to these details. Development of roller conveyor equipment specifically for foundry use has now reached a stage where any green-sand mold that will stand pouring can be rolled safely.

Roller Conveyors for Particular Purposes

57. The great number of variations in plan for this type of equipment to suit local conditions will not permit explanation

in detail in a general paper such as this. However, the extent of such mold-carrying systems is governed by the required storage.

58. The various sizes and kinds of work are classified and segregated suitably to serve molding points and at the same time be contiguous to metal for pouring. Often this general arrangement can be so worked out as to concentrate the pouring and restrict it to comparatively small areas, because of the ability to move molds in and out of the restricted pouring zones.

59. This method permits the employment of overhead means of carrying metal, with consequent greater speed of pouring, reduction of man-power, a high degree of safety and a simplicity of arrangement at moderate cost.

Floor Roller Conveyors

60. Mold-carrying systems using floor roller conveyors have the advantage of flexibility and selective directional movement to suit the day's work, and provide easy means of access to a central shakeout point. They may be fitted to premises of peculiar shape and may be operated either longitudinally or laterally or both, with molding points arranged in line for economy in sand-handling equipment.

61. Such systems may easily be altered in arrangement from time to time to suit changing conditions, or to improve the initial design in plan. This is easily accomplished, as no power applications are concerned and the equipment, being above the floor level, is quickly shifted.

62. Ease and speed of rearrangement will depend upon how well the system has been standardized with respect to dimensions, types and construction detail. A miscellaneous hodge-podge from many sources is not readily interchangeable.

FLASK STORAGE

63. Location of flask storages is highly important. They usually are planned for adjacent location and easy accessibility to molding points and to shakeout locations, in order that a circulatory movement of flasks can be facilitated, flasks going out as molds, thence to shakeout, returning either direct to molding points, or being routed through storage until required in molding department.

64. As a discontinued size is retired to storage, the required size can be sent out to molding simultaneously. Frequent changes

in flask sizes can be made quickly to suit variety of work. These movements are timed in the planning to effect practically continuous operation on miscellaneous work, with only the necessary pauses to change patterns.

65. Flask storages are equipped with conveyors placed to suit orderly piling of flasks and handy for loading and unloading. Given a clean and dry storage area, this method will result in a great reduction in flask-repair costs.

FIG. 3—HIGH-SPEED SHAKEOUT (*A*), WITH DIRECT DELIVERY OF CASTINGS TO CLEANING-ROOM ROLLER CONVEYOR SYSTEM (*B*).

66. Bottom boards, bands, jackets, etc., also are handled and stored in like manner. These methods apply, naturally, to materials that can be handled by hand. Heavier flasks and materials must be handled by the best facilities, but the same care in handling and relational locations will bring like economies.

SHAKEOUT

67. One of the most vital handling problems, purely as such, is the shakeout. This point should be easily accessible in its receiving and discharging features, and is a phase of foundry operations wherein much money can be saved. Location, function and mechanical detail will have much to do with its effectiveness as a labor saver.

68. This mechanism must be located so as to receive molds with facility, for returning flasks by uninterrupted routes to molding points or to flask storage, for discharging sand to sand conditioning system, and for discharge of castings, if of medium sizes, direct to transit means for conveyance to cooling areas and cleaning department. Mechanical means for jarring out sand should be incorporated in the structure.

69. In short-time cycles of sand movement, dissipation of heat may be effected at this point by automatic tempering devices, suitably designed for types and quantities of sand. For some types of work it is expedient to connect the shakeout with an air exhaust system for the sake of good ventilation and cleanliness. A centralized shakeout may be equipped with power conveyor feed to speed up the operation.

Equipment Features

70. Fast overhead hoists are frequently necessary to handle the larger molds and flasks in conjunction with the feed and discharge features. At the discharge side, the shakeout should be served by a means of immediate transit to keep it clear of castings as shaken out.

71. In the average run of sizes of work a uniform type of steel container is practical, constructed to run on a substantial type of roller conveyor. The container will then be a movement unit for castings of a single type or kind when quantity permits, and will traverse the cleaning room system as such, through to shipping point, and circuitously return empty to shakeout for next loading.

72. The container, as a movement unit, also will permit the use of a conveyorized cooling system, shaped to suit available area and so planned for cooling periods of varying length. This will form a continuous line or loop, with by-pass lines of sufficient capacity for the tonnage and time required.

CLEANING DEPARTMENT

73. The cleaning department in the average foundry is sadly neglected when the search for cost reductions are made. Too frequently this part of foundry work is looked upon as a necessary evil and, in cost accounting, is dumped into burden. As a matter of fact, the regular operations of getting castings into saleable shape are just as important as processes, as mold-

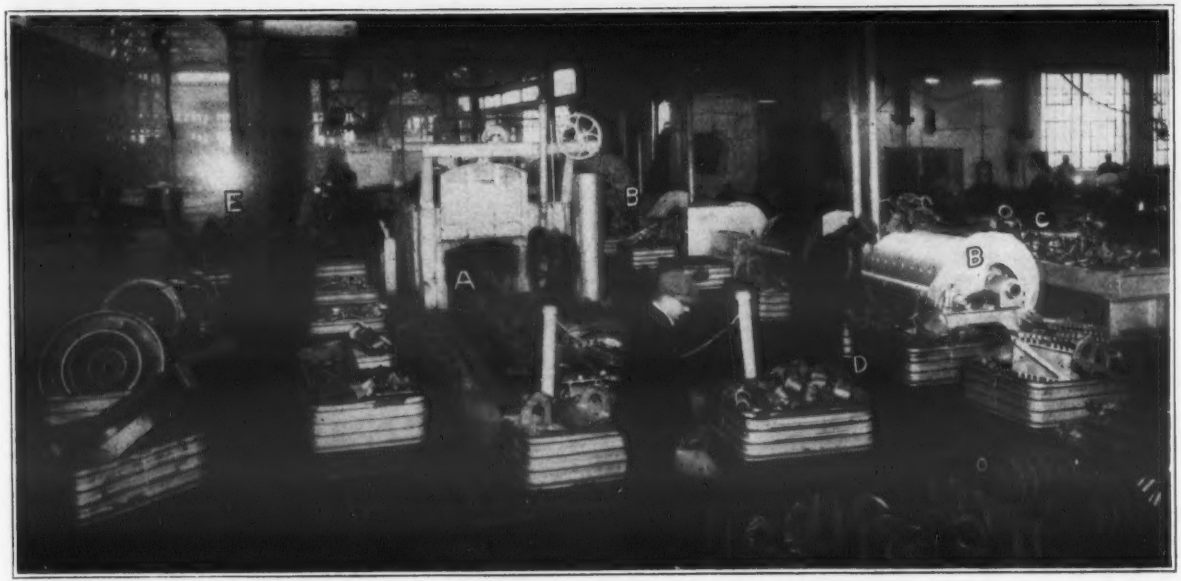

FIG. 4—DELIVERY END OF CONVEYORIZED CLEANING ROOM, SHOWING ANNEALING FURNACE (*A*). TUMBLING EQUIPMENT (*B, B*), INSPECTION (*C*) AND CONTINUOUS SORTING OF SMALL ORDERS FOR DELIVERY TO SHIPPING ROOM (*D*). CONTINUATION OF CONVEYOR LINE (BEYOND *E*) RETURNS EMPTY CONTAINERS DIRECT TO SHAKEOUT FOR RELOADING.

ing or pouring, and deserve the same attention in detail and exactitude of performance.

74. Labor in cleaning has need of the same expertness as in other operations and an equally well-planned system of process and movement. In many plants considerable improvement has been made in molding and other directly chargeable operations, only to have the indirect cleaning burden of a high cost cleaning room prove a drag anchor in total costs.

75. The cleaning room too often is the happy hunting ground of the production chaser and the nightmare of the planning department. A properly organized cleaning room needs no production chasers, nor need it interrupt production schedules.

Cleaning System Should Give Fluidity of Movement

76. This section can be a smooth outlet to shipping by providing a natural fluidity of movement adapted to the required sequences of operations, just as is done in any other manufacturing industry. Through transit, in the required number of streams of movement, can be made that will reach all areas of operations independently of each other, in a manner not to block selective despatch to any desired point.

77. In this way any number of sequences of operations may be effected, maximum flexibility obtained, and the movement of product be made progressive toward the shipping point. These methods will make an even pace and will deliver finished castings at substantially the same rate as cast, or otherwise delivered by the shakeout.

78. Scales in the conveyor lines will assure weights desired for accounting or any wage-payment plan. Positive inspection can be secured by inspection stations at required points and through which inspectors only are permitted to clear the product in transit. Defectives will be thrown out in the early stages of process, resulting in earlier recast orders and the assurance of a good product delivered to the shipping room.

Balanced Cleaning Operations

79. Such a system has the advantage of balance of operational function, the widest selectivity in sequence of process, the highest speed in transit and the lowest in costs and inventory.

80. The above references to cleaning operations might sound highly theoretical if it were not for the fact that the principles outlined have been put into practice in foundries making highly

miscellaneous work, with resulting highly satisfactory returns on the investment. The value of the shorter manufacturing cycle can be estimated only intangibly in good will of the trade through earlier deliveries.

81. The systems and principles of foundry operation described above are fully adaptable to all practical foundry wage-incentive-payment plans. It will be found that such remuneration methods will be of great assistance in obtaining the most effective operation throughout.

Good Handling Methods Increase Production

82. For purposes of comparison of ordinary production methods with well-ordered manufacture employing materials handling, planning systems, and coincidental wage plans, by employing molding operators as molders throughout the full day, the general increased production so far obtained has been better than 100 per cent.

83. Likewise, cleaning costs have been lowered between 40 and 50 per cent. Naturally, there will be variations, depending on many factors incidental to the individual plant. After fixed charges have been assessed against the investment in improvements, the earnings on these projects have run all the way from 80 per cent to 200 per cent annually.

84. For greater profits, the average foundry needs a greater net earning per operated square foot of floor space, a shorter manufacturing cycle, a reduced inventory and a reduced payroll. These necessities can be procured by the methods described above.

85. These statements are based on experience and the continued operation in actual production of similar systems in a number of foundries, over periods of several years. Another great advantage of these systems lies in safety. There has been a decided reduction of accidents, with a consequent decrease in compensation insurance costs.

Foundry Will Progress with Labor-Saving Devices

86. Looking into the future of the foundry industry, measured by any criterion of progress, it can be said with some emphasis that improvements in operations and costs are matters of urgent necessity and not choice, if the industry, as a whole, is to enjoy its rightful place in our modern arts.

87. The inception of this new life will be, unquestionably, through the general adoption and fullest employment of labor-

saving devices in movement of the great mass of materials involved in foundry work.

88. If future earnings can be measured by results thus far obtained by such means, and if foundrymen will embrace these opportunities, the future will have splendid prospects. The remedy is available and the foundry industry can "write its own ticket."

DISCUSSION

ORAL DISCUSSION

FRANK GALPI:* Mr. Campbell, what is the cost of a cleaning department—the cost per ton of cleaning, grinding, and chipping?

F. D. CAMPBELL: There is a very broad scale of costs per ton, depending on whether the product is steel, gray iron, or nonferrous, and on the range of size of product. Costs and cost reductions will also vary broadly with almost the same product, due to any number of conditions.

It is almost impossible to make a flat statement of tonnage costs without creating erroneous impressions. What we can best do is to indicate how much reduction in costs can be made from present conditions in any individual case.

I would not attempt to make a statement of what proper cleaning costs ought to be in any individual plant until it is examined. I have known some gray-iron plants to spend two cents a pound to clean castings; others, one quarter of that. This is too broad a variation for a general discussion of costs without specific details on which to base it.

J. V. HOUGH:† I am glad that the jobbing foundry was selected as a subject, because we are too prone to think of the production foundry and overlook the jobbing foundry. Also, during the past few years the jobbing man has felt that his job was really too small to think of in terms of materials handling. His work has been so varied that he felt it was impossible, and, as a result, we have had quite a high sales resistance to overcome.

However, I am sure we are getting enough installations now so that the jobbing foundryman can see what is being done. This is more convincing than any other method of getting his ear.

There is one point I want to mention that I do not believe Mr. Campbell covered. We were just called in by a jobbing foundry to equip with roller conveyors for mold handling where the saving to the man was the important feature.

It is in a steel plant foundry, where the heat conditions are terrific

*Forest City-Walworth Run Foundries Co., Cleveland.
†Mathews Conveyor Co., Ellwood City, Pa.

in the summer time, and this conveyor system will take the molds as soon as they are poured. The molding floor is quite a distance from the molding operator and molding machine. As soon as the mold is poured it is removed immediately from the vicinity of the machines and a great deal of heat is taken away from the operator.

That is just a little point in saving the operator. The big item, of course, is cutting the cost of making the molds through the use of materials handling, and that is what we all are trying to do.

In the matter of accuracy of equipment, the question often comes up in the jobbing foundry, "Can you handle snap flasks?" We have found that in the great majority of cases we can handle snap flasks on roller conveyors. There are, of course, some molds which have delicate, suspended green cores that cannot be handled.

We don't attempt to prescribe the accuracy of a roller conveyor. We do attempt to examine carefully the mold that must be handled, and then we can state whether we can handle it successfully or not.

There are all sorts of claims made today. Certain foundrymen are requesting certain tolerances, some of them absurd. We are given tubing by the tube manufacturers that conforms to certain tolerances, and unless foundrymen want to pay for a turned roller and one that is built by hand, we must stick within those limits of tolerance which are commercial.

Thus, if the materials-handling equipment manufacturer does not state tolerances in his equipment, please do not insist on them. We have to stick to limits that are commercial, but we will tell you whether we can handle your products successfully, and that is the answer.

F. D. CAMPBELL: In the solution of any foundry problems, do not forget that it will be necessary for the foundryman to supply about 50 per cent of the hard work in order to get the best results. The outside man cannot take on the complete burden. He must be assisted in a great many ways, first, by freedom and an open mind, not letting the fact that it was not done this way twenty years ago interfere with trying to find a better way to do it; and by maintaining a mental alertness to seize upon practices or principles of operation, even of other industries quite foreign to the foundry industry. Many other industries have been able to perfect methods that may be applied, with some modifications, to foundry operation.

S. G. KOON:* I was very much impressed, among other things, with the absence of smoke and soot in the foundry described by Mr. Campbell. I could see long distances through the aisles without my view being blurred. They seemed to get everything out of the way quickly, and the hot sand drops down through the shakeouts and goes up the incline to the conditioning machinery. The smoothness of operation is one thing which was particularly noticeable, as well as the fact that they have opportunity for expansion of the various movements that may be required.

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The Continuous Process as Applied to Malleable Practice

By B. R. Mayne,* Saginaw, Mich.

Abstract

The need for a continuous pouring system in this malleable foundry led to an investigation of melting methods to give a continuous supply of metal for pouring. The system finally adapted provided for the use of cupolas for melting the cold stock, and refining and raising the temperature in electric furnaces.

Cupolas are supplied with forehearths in which a soda-ash flux is used to reduce the sulphur content of the metal. The electric furnaces are lined with silica; data on life of refractories in the various positions are given. Metal stock used consists of pig iron, alloy-free flashings, pressed-steel bundles and rails, hard-iron remelt and soft-iron scrap.

Hand cupola charging at present is considered most economical. Cupola blast pressure is somewhat lower than in ordinary gray-iron practice, due to open nature of the charges. Iron at the cupola spout averages 2800 degs. Fahr., and from the electric furnaces, 2950 degs. Fahr. Three tons of hot metal are taken at one time from the 10- to 12-ton supply in the furnace.

Very close laboratory control of both the cupola iron and that in the electric furnace is necessary. From standpoint of uniformity of cupola operation, quality of coke is most important, and routine test used is that for combustibility. Production of iron at the blast furnace is carefully watched. Mechanical equipment used is shown in accompaning illustrations.

1. The trend of modern industry is to produce a better product at a lower cost. In the past, malleable foundries did not give a great deal of thought to conveyor equipment, although by its use many gray iron plants were reducing their molding costs considerably.

* General Manager, Saginaw Malleable Iron Division, General Motors Corp.

2. We were melting daily around 200 tons of iron in our four oil-fired air furnaces. This melting equipment did not seem feasible for continuous melting, and it was deemed necessary, therefore, to look for a process that would give a continuous supply of hot iron and would also be flexible so that production could be varied up to 40 tons per hour.

3. A steady supply of good metal is essential to the success of continuous molding operation. Various processes were considered before deciding on one that would result in a satisfactory iron at a cost comparable with that of the air furnace, or, more essential, one that would produce iron in the ladle at a lower cost per ton than the air-furnace process.

4. Numerous processes could be used to produce a satisfactory iron, but when all items were considered—such as supply of raw material, flexibility of operation, cost of metal at the spout, quality of iron and other factors—we decided on the cupola-electric process, or, as it is commonly referred to, the "duplex process for making malleable iron."

Tests Assure Practicability of Process

5. Before making extensive changes in our plant, we conducted a series of tests at the research laboratories of the General Motors Corp., to assure ourselves of the practicability of this process, which had previously been tried out in Europe, and where it failed to produce a commercial malleable iron. From the beginning, our tests proved that the process had possibilities, and within a few weeks we were producing a good commercial malleable iron.

6. With the preliminary work completed, the next step was to lay out the process on a commercial basis to fit into the building already constructed at our plant. Part of the old foundry was used for the mold conveyors and a new building was constructed for the melting department, which housed the cupolas, electric furnaces, transformers and generators.

Cupola Melting Equipment

7. Our melting equipment consists of three 90-in. shell cupolas; three 10-ton, oval-shaped, electrically-tilted forehearths; one 3-ton electric crane to transport the cupola metal to the electric furnaces, and two 3-ton electric furnaces. Two rotary-type blowers furnish the blast for the cupolas. A 10-ton electric crane unloads all the raw materials for melting and places them in the proper storage bins.

8. The storage space for the various pig irons and scrap is very limited, which makes it necessary to keep a close check on the raw materials received. The inventory is kept low, with only two or three days' run in the yard at any one time.

9. Our cupolas are lined down to 66 inches and have a melting capacity of 20 tons each per hour. Two of the three cupolas are used daily during normal operation; the third cupola is repaired during the day, and one used during the day is repaired at night. A complete repair in the melting zone is required at the end of each day's run.

10. The slag conveyor is at the rear of the cupolas. The molten slag drops from the slag spout into a trough of water, a moving chain in this trough collects the slag at one end of the system, and it is from this point that the slag is hauled away. This arrangement simplifies the handling of the slag and makes conditions more pleasant for the cupola men. Each of the three forehearths holds 10 tons of molten iron, and they are lined with a 9-in. wall.

Electric Furnace Capacity and Power

11. The two electric furnaces are rated at a 3-ton cold-melt capacity, but they hold from 10 to 12 tons of molten metal. Each furnace has a 1500-kilovolt-ampere 3-phase transformer which steps the voltage down from 5100 to 115 volts. A "Limuter" was recently installed on one of the furnaces, and it has been found quite successful in keeping down the demand.

12. By close supervision it has been possible to hold the power peak down to the desired point. This has had the effect of holding down the kilowatt-hour consumption, which varies somewhat according to the tonnage.

13. When operating the furnaces near capacity, the kilowatt-hour consumption per ton of hot metal tapped, which includes about five per cent cold-steel scrap, runs from 92 to 98. When operating at reduced capacity, the power consumption will run as high as 120 kilowatt-hours per ton.

Refractories for Electric Furnaces

14. From five to six pounds of graphite electrodes are used per ton of hot metal. Scrap electrodes are used for burning-in of holes in the bottom, which is rarely done. Silica brick is used for refractories on the electric furnaces.

15. The life of the roof is from four to seven weeks, during which time 2500 to 5000 tons of molten iron are poured from the furnace. The life of a side-wall is longer in most cases than is the life of the roof. The bottom is made up of two layers of clay brick, on top of which are fused layers of ganister running about eight inches thick.

16. Proper operation of the furnace is the greatest factor in increasing the life of refractories. The furnace is operated free from slag at all times. To keep the slag off the hot iron, the furnace operator tilts the furnace backward and uses a green pole to remove floating slag from the metal.

Capacity of Output

17. A maximum of 425 tons of metal has been poured in 10 hours. The floor space of the present conveyor system is half of what was formerly used for floor molding, with more than double the former production.

Material Used

18. Since starting the production of cupola electric, we have used a variation of material. At present we have standardized on two grades of pig iron, alloy-free flashings, pressed-steel bundles and rails, besides our hard-iron remelt and soft-iron scrap.

19. This material is placed in bins, either on the ground or charging floor, by means of the 10-ton crane. The charge is loaded on steel trucks by the charging crew. These trucks are pushed onto a dial scale where the charge is carefully weighed, and then are moved to the cupola charging floor where the material is manually charged.

20. Three of these dial scales are used for weighing the metal charge, and one for the coke charge. The scales are checked hourly by the weigher and all discrepancies immediately taken care of.

Charging Practice

21. Considerable thought has been given to automatic charging, but so far only preliminary work has been done. The nature of the charge differs from that used in most foundries where a large percentage of pig iron is used.

22. Our charge consists of 10 to 12 per cent pig iron, 38 to 40 per cent steel scrap and 50 per cent hard-iron sprue. Most of the steel in the charge is made up of flashings, which are very

bulky and do not lend themselves to automatic charging as readily as would appear.

23. The coke arrives at the plant in drop-bottom cars, which are unloaded by a skip hoist into a storage bin holding about two and one-half cars of coke. At the bottom of this storage bin are three hoppers, from which the coke is loaded into the coke buggies, weighed and charged into the cupolas.

24. The bed takes about 4000 lbs. of coke, with 320 to 360 lbs. between the 4000 lbs. of metal charged. Limestone is supplied to the charge floor by means of the 10-ton crane. A trip bucket is filled with limestone on the ground, raised to the charge floor and shoveled onto the pile used to supply the cupola.

Reduction of Sulphur

25. Fig. 1 shows layout of the three cupolas, three forehearths and one electric furnace. A second electric furnace is located on the opposite side of the transformer room.

FIG. 1—ARRANGEMENT OF MELTING UNITS, SHOWING THREE CUPOLAS AND THEIR RESPECTIVE FOREHEARTHS AT RIGHT, AND ONE ELECTRIC FURNACE (LEFT, REAR). THE SECOND ELECTRIC FURNACE IS LOCATED ON THE OTHER SIDE OF THE TRANSFORMER ROOM.

26. The molten cupola iron flows into the forehearth. Soda ash, which is used to desulphurize the metal, is placed in the spout, melted and washed into the forehearth. The soda-ash slag is allowed to remain on the metal from 1 to 1½ hours before being skimmed off. Approximately 20 per cent of the sulphur is removed by using about six pounds of soda ash per ton of iron treated.

27. The operation of the cupola is very similar to that in gray-iron practice, but the blast pressure is somewhat lower, due to the open charge, and averages about eight ounces while melting 16 tons per hour. The maximum blast does not go over 13 ounces at any time.

Metal Control

28. The temperature of the iron at the cupola spout averages 2800 degs. Fahr. During the time the metal is in the forehearth before being taken to the electric furnace, the temperature drops 100 degs. Fahr. during normal operation. The cupola metal is transferred by means of a 3-ton crane from the forehearth to the electric furnace along the monorail shown in Fig. 1.

29. The furnaces are filled with molten iron in the morning. When pouring is started, three tons of hot iron at about 2950 degs. Fahr. are taken out of one furnace, leaving about seven tons in the furnace. Three tons of cold cupola metal are added to this furnace and the other is tapped while the furnace receiving the cold metal is getting hot, which takes about four minutes.

30. Three tons of iron from each furnace are poured alternately in this manner until the end of the day, when the furnaces are emptied. By this arrangement a continuous supply of uniform iron is given to the foundry throughout the day.

Laboratory Control

31. The duplex process for making malleable iron requires very close laboratory control of all raw materials and molten iron. This is true of every metallurgical process, but in air-furnace melting formerly carried out in our plant—and which is the practice in other plants—preliminary samples were taken for chemical analysis of the molten iron before being poured into molds. If the analysis was not as desired, the necessary additions could be made before tapping.

32. It is our practice to take chemical samples from the cupola iron every 20 minutes throughout the day. The iron being

analyzed is poured into molds before the analysis is completed, and the routine analysis therefore serves only as a guide.

33. The analysis when reported represents iron that was charged in the cupola about one hour and forty-five minutes before. It takes about an hour for the charge to descend in the cupola, 10 minutes in the forehearth and 35 minutes for a complete chemical analysis. Chemical analyses covering carbon, silicon, sulphur, manganese and occasionally phosphorus are made on six samples of iron taken daily from each electric furnace.

Coke Requirements

34. The analysis of the raw material covers coke, pig iron and the various steels used. From the standpoint of uniformity of cupola operation, quality of the coke is the most important.

35. We have found that the most reliable routine test for coke is the combustibility test. A fast-burning coke is desired, as we can melt faster and thereby use less coke. A coke with a temperature rise of 250 degs. Fahr. in two minutes requires about 300 lbs. of coke per 2-ton charge, while a coke with a temperature rise of 250 degs. Fahr. in four minutes requires about 400 lbs. of coke per charge. From the standpoint of quality of iron produced, both cokes will give equally as good metal.

36. The purpose of the coke testing is to try to get the producer to supply a uniform coke. It can readily be appreciated that uniform cupola operation cannot be expected with a coke showing a variation of two minutes for a 250 deg. temperature rise. It is our practice to change the amount of coke used in the charge to conform with the carbon content of the iron which we plan to pour at the spout of the cupola.

37. On all coke tests, the total temperature rise and ignition point are carefully noted and studied. The combustibility test used for coke is that described by A. L. Boegehold in an appendix to his paper [1] presented at the 1929 meeting of the American Foundrymen's Association.

Production of Iron at Blast Furnace

38. The control of our pig iron starts with the study of the iron ore used at the blast furnace. Our metallurgist is at the blast furnace during the time the pig iron is cast, in order

[1] Boegehold, A. L., *Quality of Iron as Affected by Blast Furnace Practice*, TRANSACTIONS, A. F. A., vol. 37 (1929), appendix pp. 148-152.

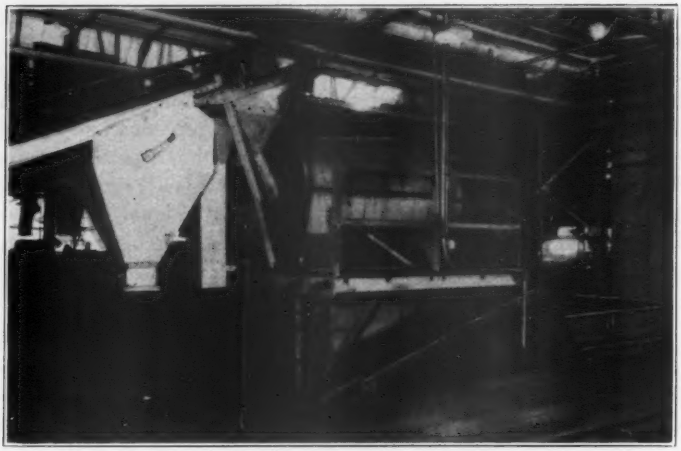

FIG. 2—PRIOR TO ITS USE IN MOLDING OPERATIONS, THE SAND IS INITIALLY PREPARED IN A MAGNETIC SEPARATOR, SCREEN, TEMPERING BELT AND PADDLE MIXER.

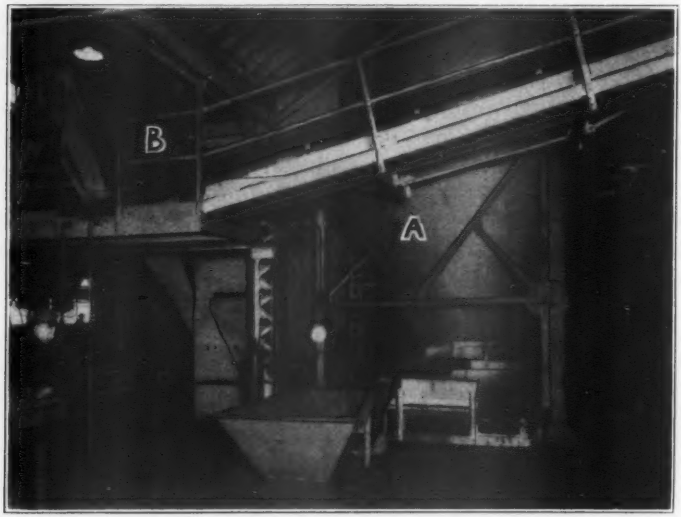

FIG. 3—VIEW SHOWING SAND STORAGE TANK ("A") AND DISTRIBUTION OF SAND TO TWO MOLDING UNITS. HERE SAND IS FINALLY TEMPERED AND AERATED FOR DELIVERY TO HOPPERS OVER THE MOLDING MACHINES. AN OPERATOR ("B") ON AN ELEVATED PLATFORM RECEIVES A BONUS FOR HOLDING MOISTURE CONTENT OF THE SAND AT A FIXED PERCENTAGE, WITHIN 0.1 PER CENT.

to get all the information necessary for a study of the quality of pig iron produced. The various casts of iron are followed through the melting and annealing processes.

39. We have found that variation in operation of the blast furnace and composition of the burden bear an important part in production of sound castings which will readily anneal. The machinability of the annealed casting is also dependent to a more or less extent upon the blast-furnace practice and quality of pig iron used.

40. When the pig iron arrives at our plant, a chemical analysis is made of three pigs from each car, to check the blast-furnace results. It was formerly necessary to take the analysis of at least ten pigs from each car, but the blast furnace people now have taken steps to produce a more uniform pig iron by pouring casts from an 80-ton ladle.

Steel Grades Used

41. In the duplex process we use various grades of steel. The largest percentage used in the charge is flashings produced at various drop-forge plants. We specify alloy-free flashings, but it is necessary to keep a close watch on this material as it arrives at our plant, because very often some alloy flashing is mixed with the plain carbon flashing.

42. This is the only precaution taken on our steel. Rails, sheet bundles, angle bars, boiler plates, etc., do not contain any alloys and the only cause for their rejection is in the case of excessive rusting.

Foundry Processes

43. The sand is first prepared for use by means of a magnetic separator, screen, tempering belt and paddle mixer. This layout is shown in Fig. 2.

44. Fig. 3 shows the storage tank and distribution of the sand to two molding units. At this point the sand is finally tempered and aerated for delivery to the hoppers over the molding machines.

45. An operator stationed on an elevated platform regulates the water from that point to hold the moisture in the sand to within 0.1 per cent. He is paid a bonus to hold the moisture content at a fixed percentage.

46. Fig. 4 shows delivery of the prepared sand from overhead hoppers to the flasks by means of a conveniently located lever.

FIG. 4—OVERHEAD HOPPERS DELIVER PREPARED SAND TO FLASKS BY MEANS OF LEVER HANDY TO THE MOLDER. EVERY MOLDING STATION IS ADJACENT TO ONE OF THE MOLDING CONVEYORS WHICH CARRY FINISHED MOLDS TO POURING ZONE.

FIG. 5—VIEW OF TWO POURING STATIONS *(A, B)*. POURERS STAND ON MOVING PLATFORM AND POUR OFF MOLDS CONTINUOUSLY. LADLES TRAVEL ON ELECTRIC HOISTS OPERATING ON OVERHEAD MONORAIL LOOPS. POURING PLATFORM AND MOLDS MOVE AT SAME TRAVEL SPEED.

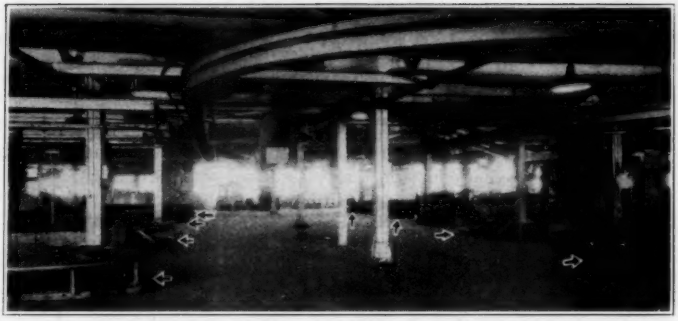

FIG. 6—A VIEW OF ALL EIGHT POURING STATIONS (INDICATED BY ARROWS) ON TWO OF THE MOLDING UNITS. HOT METAL COMES FROM ELECTRIC FURNACES IN LADLES TRAVELING ON OVERHEAD MONORAIL LOOP SHOWN ABOVE.

We have a total of 112 molding stations and each station is located alongside one of the molding conveyors, thus enabling the molder to place his completed molds on the conveyor by taking only a few steps.

Pour from Movable Platforms

47. The molds travel on the conveyor to a pouring zone (see Fig. 5), where the pourers stand on a moving platform and

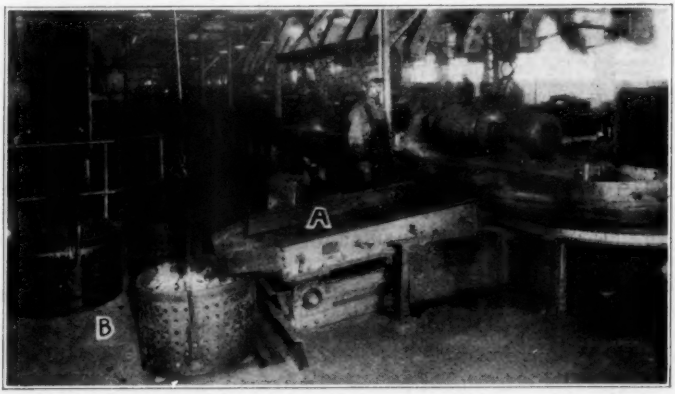

FIG. 7—MOLDS COOL ON RETURN TRIP OF MOLD CONVEYOR AND THEN DUMP ONTO VIBRATING SHAKEOUT SCREEN (*A*). SAND IS SCREENED OFF WHILE CASTINGS DROP INTO BASKETS (*B*) PERFORATED TO HASTEN COOLING. THESE BASKETS TRAVEL ON TROLLEY CONVEYOR OUTSIDE BUILDING FOR COOLING, THEN TO CLEANING ROOM AND BACK TO VARIOUS SHAKEOUTS FOR RELOADING.

pour them off continuously by means of ladles carried by electric hoists operating on an overhead monorail loop. The pourers' platform moves at the same travel speed as the molds.

48. Fig. 6 shows all of the eight pouring stations on two of the molding units. It also shows the overhead monorail loop on which the ton ladles travel in bringing the hot metal from the electric furnaces.

Conveyor System Is Complete

49. The molds are cooled on the return path of the mold conveyor, and at the end they are dumped onto a vibrating shakeout screen, shown in Fig. 7. The sand discharges through the screen, while the castings free from sand are discharged into baskets which have perforated plate sides to hasten the cooling of the castings.

50. These baskets are carried by means of a trolley conveyor to the outside of the building for cooling. Then they go to the cleaning room, where they are dumped. From this point the empty baskets are returned to the various shakeouts for reloading.

Annealing

51. Leaving the cleaning department, the castings arrive on a belt conveyor in the annealing room. The annealing process has been continuous for years. Three oil-fired kilns of the pusher-car type anneal all the castings.

52. The two larger kilns are each 347 ft. long and are regularly operated on a 96-hour annealing cycle, but have produced consistently good iron on a 90-hour cycle, which is equivalent to 65 tons of castings daily from each kiln. The other kiln, 180 ft. long, has operated for months on an 80-hour cycle and occasionally on a 72-hour cycle, with excellent results. On the latter schedule approximately 40 tons of castings can be annealed daily.

53. The matter of continuous melting, molding, pouring and annealing is of particular interest to the malleable industry of today. Production and cost records prove that the money invested in our continuous-process equipment has been fully justified. Further strides along these lines will present themselves as time goes on, and the malleable industry should be ever alert to make use of any equipment which tends to give a better product at a lower cost.

DISCUSSION

ORAL DISCUSSION

C. F. JOSEPH:* In the foundry of the Saginaw Malleable Iron Division of General Motors Corp., the melting, molding and annealing is so arranged that in making castings, from the raw material to the finished product, the material is practically in motion all the time. From the storage bins on the charge floor, the pig iron, steel and sprue are loaded on trucks, weighed and charged into the cupolas.

The operation of the cupola is very much the same as that followed in gray-iron practice, except that, due to the nature of the charge, a lower blast pressure is used. The coke is the most important item of all raw materials to watch from the standpoint of uniformity, since carbon control depends almost entirely on the quality and quantity of coke used.

The molten iron, leaving the spout of the cupola, is desulphurized and passes into a forehearth, where it is stored for transfer to the electric furnaces. The molten iron is taken to the electrics, superheated between 2900 and 2950 degs. Fahr., and then taken to the molding conveyors in ton ladles by electric cranes.

At the pouring stations the metal is transferred into 300-lb. ladles and the molds poured off continuously from a moving platform. After the molds are dumped, the castings are taken away on a cooling conveyor to the cleaning and annealing rooms. The continuous annealing kilns have been in operation for a long time.

The control of the temperature is such that a superior product is produced over the periodic ovens formerly used. The annealing time has also been cut to three and four days.

The annealed castings are dumped onto a belt conveyor. Most of the castings weighing over three pounds have test lugs. These lugs are broken off and the gates sheared and ground off. All of the castings are ground in the soft and are then cleaned. The castings are next taken to the various presses for straightening, and are then ready for shipment.

MILTON TILLEY:† Mr. Joseph, you stated that, due to the nature of the charge, you used a lower air blast in the operation of the cupola. Will you tell us why this lower blast is used?

C. F. JOSEPH: The charge which we use consists principally of material which is loose—for instance, steel flashings. We use around 20 per cent flashings, and naturally, with the amount of air going through the cupola using flashing, there is not as much chance of building up a pressure in the cupola. We use a blast pressure of around 12 ounces when melting around 22 tons an hour in a 60-in. cupola, whereas the gray-iron cupolas running that many tons use a blast pressure of around 28 ounces.

MEMBER: How many molds are there ahead between the molders on

*Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.
†National Malleable & Steel Castings Co., Cleveland.

the conveyors and the pouring position? Also, how many molding conveyors are there, and how much time is allowed for the interim between delivering the metal from the electric furnaces to each batch of molds on each conveyor?

C. F. JOSEPH: We have 11 molding conveyors with a total of 112 stations, and there are possibly six molds between the time the last mold is covered on the conveyor until the first mold is poured off. There are about six molds between the time the last mold is poured.

The cope is placed on the drag and there is a distance of about six molds, and between the time the iron leaves the electrics there is just enough time for the electric crane to travel possibly 25 feet. Then the iron is transferred from these ton cranes into 300-lb. ladles, from which the molds are poured off.

MEMBER: In pouring small castings, how many ladles is it practicable to pour from one of the 300-lb. ladles?

C. F. JOSEPH: I should say that there are as many as 20 molds poured from a 300-lb. ladle at times, when the casting is small and the mold does not take much iron.

That is one reason why we have to heat our iron to such a high temperature. These temperatures that I speak of were taken with an optical pyrometer. The iron leaves the electrics accurately between 2900 and 2925 degs. Fahr. That is where we try to hold it. Some times it goes even higher than that.

When we first started this process, about four or five years ago, we poured the iron a great deal colder and we did get, of course, many misruns and lots of slag in the castings. Now our misruns are down to nothing, and that is due entirely to the fact that the iron is hotter.

MEMBER: Will Mr. Joseph tell us how low he keeps his carbon in the iron as poured from the cupolas?

C. F. JOSEPH: It is possible to make any carbon iron in a cupola, but we run right around 2.60 to 2.80 per cent. We try to hold it on the low side.

MEMBER: Mr. Joseph, you speak of temperatures of 2800 degrees from the cupola. You mean you get that right along, or just occasionally 2800?

C. F. JOSEPH: No, we have a man who works between the cupola and the electrics every day. We are interested, of course, in trying to keep the iron from the cupola as hot as we possibly can, because if it is cold we have to heat it up in the electric. Therefore, we watch that very, very closely, and the temperature of the iron at the cupola spout depends almost entirely upon the kind of coke used.

We have used a certain kind of coke which would give us iron at the spout as high as 2900 degrees practically all day. That does not seem reasonable, but we have done that. At the present time, with the coke that we are using, the iron at the spout runs around 2800 degrees. It may vary within 20 degrees higher or lower at times, but it runs fairly consistent at 2800.

MEMBER: You use the usual correction factor for molten metal?

C. F. JOSEPH: Yes, we do. The actual reading on this optical (the Siemens & Halske) is around 2620 degrees, and we are supposed to add around 200 degrees at that temperature.

MEMBER: Have you ever compared that with the Leeds & Northrup?

C. F. JOSEPH: Yes, we have, and it reads exactly the same. We had a Leeds & Northrup at our plant for a couple of months and we checked it exactly with this other instrument.

MEMBER: What are some of your low temperatures, for instance, from the cupolas?

C. F. JOSEPH: We have used certain kinds of coke where it would run as low as 2650 degrees. The coke of which we use the least amount is a rapid-burning coke. When we use a slow-burning coke, we get hotter iron than the other, and we use more of it, of course, in order to hold our carbons up.

MEMBER: You speak of desulphurizing in the ladle or forehearth. How low do you get your sulphur at that point?

C. F. JOSEPH: We add the purite in the spout of the cupola and it comes from the cupola round 0.10, and we get it out around 0.08. At times it comes from the cupola between 0.10 and 0.11, and from the electric about 0.08 to 0.09.

MEMBER: Is the silicon oxidation very high in your charge?

C. F. JOSEPH: Yes, it is very high.

MEMBER: You get a large amount of heating effect from the oxidation of the silicon?

C. F. JOSEPH: The iron coming cold, the silicon is lower.

MEMBER: What do you call high oxidation there on your silicon, normally?

C. F. JOSEPH: Around 30 or 50 per cent, depending upon the kind of charge we use.

MEMBER: 0.30?

C. F. JOSEPH: If you figure in points lost, it would run between 0.30 to 0.40.

G. M. THRASHER:* I have operated cupolas on malleable for light work for a good many years, and I find that for the kind of work we make the loss is only about 0.10, so that we have to depend almost entirely on coke for heating. We do not get any heating effect from the oxidation of silicon. We do not get a highly oxidized metal at the spout, but we do get considerable sulphur absorption on account of the higher coke consumption.

C. A. DEMMLER:† You spoke of grinding the castings in soft iron. Do you find that more economical than hard iron?

C. F. JOSEPH: Yes, we do.

MEMBER: Why?

*Kennedy Valve Mfg. Co., Elmira, N. Y.
†Walworth Company, Kewanee, Ill.

C. F. JOSEPH: The cost of grinding in the hard iron is a whole lot higher than in the soft iron on wheels alone. For instance, I know some jobs where we used to have a cost of, say 28c to grind a hundred pieces, and this cost has been cut to something like 10c. It is much less from the wheel standpoint.

MEMBER: What are your high and low limits in your carbon as it comes from the cupola?

C. F. JOSEPH: I believe that the average over a day's run can be held within 20 points.

MEMBER: Do you keep your iron in your hearth or take it out as you melt it?

C. F. JOSEPH: The iron runs from the cupola into a 10-ton forehearth, and there it is held until they are ready for it at the electrics. We take it from the forehearth over to the electric in 3-ton ladles.

MEMBER: How high is it from your charging floor to your tuyeres?

C. F. JOSEPH: Nineteen feet.

W. R. BEAN:* In connection with Mr. Demmler's question, possibly I might throw a little light on this. The apparent difference and the difference in practice is in the removal of a small amount of metal, which I believe is Mr. Demmler's condition—not very heavy gates on small castings, against heavy gates on large castings.

I believe it is true that the grinding can be done to better advantage in the hard than in the soft and light castings, whereas on heavier castings there is very little question but that the grinding can be done for less money after annealing. It does not leave as good a finish, however—grinding in the hard is particularly advantageous where finish is desired, because it is done before annealing and there is no burr or no fin left from the grinding in the hard as there is in the soft. I think possibly that may help explain the grinding situation.

MEMBER: Do you stagger the operation of those two electric furnaces so as to deliver hot metal with greater frequency, or do you operate them simultaneously and independently?

C. F. JOSEPH: Both of them, of course, have molten iron in them; but we tap three tons out of a bath of about 12 tons from one, and then put three tons of cold metal back into the one from which the metal was taken. Then we take out three tons from the other one, out of a bath of 12 tons, while the first one is coming up to heat. Thus, at all times eight tons are left in the furnace while three tons of cold metal are being transferred over.

MEMBER: How long does it take, after you make the charge of the colder metal, to have the metal ready for pouring out of the furnaces?

C. F. JOSEPH: It will average about four minutes. We are putting three tons of cold metal into a bath of eight tons of hot metal, which gives us 11 tons of metal, and it does not take very long for it to get hot. We have, at times, done it in less than four minutes.

*Grindle Fuel Equipment Co., Harvey, Ill.

A Standard Cost System for Gray Iron Foundries

The standard cost system for gray iron foundries which appears on the following pages was formulated by the Gray Iron Institute of Cleveland, and has been recommended by the Foundry Cost Committee of the American Foundrymen's Association for use in all gray iron foundries. This recommendation is printed below, preceding the system itself.

TO THE MEMBERS OF THE AMERICAN FOUNDRYMEN'S ASSOCIATION:

The Standard Cost System for Gray Iron Foundries described in this paper, was prepared by the Gray Iron Institute, Cleveland, and is recommended for use in all gray iron foundries by the Cost Committee of the American Foundrymen's Association.

This system has all the features which make it possible and practicable for the entire gray iron industry to adopt it. In its simplest form, any small jobbing foundry can install it without fear of excessive clerical expense, complicated procedure or unnecessary detail. In its more advanced form, it can provide large foundries with any desired amount of detailed information.

We urge all gray iron foundries to adopt the system, and feel sure that its use by a steadily increasing number of foundries will not only be of great benefit to the gray iron industry, but will react favorably on all branches of the foundry industry.

A. E. HAGEBOECK, *Chairman,*
A. F. A. Foundry Cost Committee.

R. E. Belt,
W. J. Grede,
W. J. Corbett,
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A Cost System for Gray Iron Foundries*

ADVANTAGES TO THE INDIVIDUAL FOUNDRY OF GOOD COST ACCOUNTING

The value of good cost accounting methods to any business is generally recognized by all up-to-date business men. Government investigations in many industries have shown that concerns

*Formulated by the Gray Iron Institute, Terminal Tower Bldg., Cleveland

which have adopted good cost accounting methods are much more likely to prosper than those who guess at their costs. Some of the chief advantages of a good cost accounting system are as follows:

1—It provides an accurate basis for the estimating of selling prices.

2—It eliminates guess-work and the basing of quotations on competitors' prices, as reported and frequently misrepresented by buyers.

3—It shows up profitable and unprofitable lines of work.

4—Monthly cost reports showing variations of major cost items from former figures, or from predetermined standards, are an invaluable aid to the management in reducing costs, eliminating waste and generally controlling the efficiency of labor and the consumption of materials.

ADVANTAGES TO THE INDUSTRY OF A STANDARD COST SYSTEM

A standard cost system provides the "one best way" known to the industry to figure costs.

Foundries that have no cost system but desire to install one will be provided with a correct system based on the best standard practice and experience of others, thereby eliminating expensive individual and independent experimentation. This should encourage and accelerate the adoption of accurate cost methods by many foundries that heretofore have been unable to secure such information from any source, or with any confidence that the method suggested was "standard practice."

Uniformity in cost accounting methods can only be attained by the recognition of some one system as "standard." The Gray Iron Institute system is the only standard system for gray iron foundries which has any organized backing. Its main features are practically identical with the best current practice now in use by the most up-to-date gray iron foundries. It will be kept up-to-date and revised whenever revisions prove necessary or advisable.

For these reasons we believe it will be recognized as "standard" for the gray iron industry and adopted by a great majority of gray iron foundries. Those few foundries who may be unwilling, at the present time, to adopt it, will tend to fall in line as its use becomes more general and the advantages of a uniform

cost accounting system throughout the industry become more apparent.

ADVANTAGES OF UNIFORMITY IN COST ACCOUNTING PRACTICE

1—Ridiculous prices based on guess-work and ignorance of true production costs will be eliminated.

2—Foundries having similar actual costs will tend to quote approximately similar prices.

3—Differences in price will be based on differences in efficiency of operation, instead of on differences in the method of figuring the cost. Competition will then be on a sound and legitimate basis, and the market for gray iron castings will be greatly stabilized.

4—Buyers of castings will be inspired by a new and heretofore unknown feeling of confidence that prices quoted are based on a real knowledge of costs.

5—Foundries using a uniform cost system will be able to compare costs with each other with the assurance that each item of cost is figured by the same method. This fact undoubtedly will speed up the formation of local cost groups in many foundry centers.

6—Comparative cost reports will enable each foundry to compare its major items of cost with the average lowest costs reported by the local foundry group, thereby providing an invaluable aid in locating abnormally high items of cost and reducing them to figures which others have attained. The tendency will then be to raise the level of efficiency of the whole group, thereby enabling the foundrymen to meet more effectively competition from other districts and from competing industries.

7—This association, in local groups, will also tend to change a spirit of antagonism and distrust, which too often exists in foundry centers, into a genuine feeling of friendliness and co-operation, and will thereby gradually strengthen the morale of the entire industry.

COST DIVISIONS OF THE FOUNDRY

General Overhead Expense

General Overhead Expense includes all the items of cost and expense not chargeable specifically to one of the manufacturing or auxiliary departments. Such expenses are:

Taxes (except federal and state income taxes)	General Labor
Insurance	General Repairs
Depreciation	General Office Expense
Heat	Administrative Expense
Light and Power	Advertising and Selling Expense
General Supervision	Compensation Insurance
	Loss on Bad Debts

Four Main Departments

The Manufacturing Departments are the four main productive departments and are the same for the simplest or the most elaborate accounting system. They are:

1—Melting Department
2—Molding Department
3—Core Department
4—Cleaning and Shipping Department

Possible Subdivisions of Main Departments

Any of the four main departments may be subdivided into as many classifications or divisions as desired. The following subdivisions are only suggested, as their use is entirely optional with the local foundry:

Molding Department

2 A—Heavy Floor (under crane)
2 B—Light Floor (not under crane)
2 C—Bench
2 D—Squeezer Machines
2 E—Jolt Machines (or other heavy machines)
2 F—Sandslinger

Core Department

3 A—Bench
3 B—Floor
3 C—Machine

Cleaning and Shipping Department

4 A—Cleaning Department (tumbling, sandblasting, pickling)
4 B—Finishing Department (grind, chip, file, sort, inspect)
4 C—Shipping Department (packing, shipping)

Auxiliary Departments

The Auxiliary Departments are those that contribute to the proper functioning of the manufacturing or productive departments. Auxiliary departments may be used and their number and functions are optional and dependent only on the detail desired. Among the most common auxiliary departments are:

5—Carpenter Shop
6—Pattern Shop
7—Maintenance Department
8—Heat, Light and Power Department.

Special Cost Divisions for Special Manufacturing Operations

Special manufacturing, assembly or finish operations—such as machine work, assembling, japanning, plating and annealing—are not part of the foundry operations and must be considered as separate manufacturing operations, independent of the foundry.

DEFINITION OF DEPARTMENTS

1. *Melting Department*

The Melting Department includes the cost of all

Metals
Fuels
Repairs
Supplies
Conversion cost

The Conversion Cost includes labor and power beginning with the assembling of the melting stock and the fuel at the place of storage, ending with the delivery of the molten metal into the ladles at the spout of the cupola or furnace.

2. *Molding Department*

The Molding Department includes the following:

Direct molding labor
Expense labor
Repairs
Supplies

beginning with the transportation of the molten metal from the spout, the pouring of the metal, the preparation of the molding sand; ending with the delivery of the castings into the Cleaning Department.

3. *Core Department*

The Core Department includes the following:

Direct core-making labor
Expense labor
Repairs
Supplies

beginning with the mixing of core-sand mixtures; ending with the delivery of the finished cores to the Molding Department.

4. *Cleaning and Shipping Departments*

The Cleaning and Shipping Department includes the Direct Labor and Expense Labor of the following:

Tumbling	Inspecting
Sandblasting	Shipping
Grinding	Repairs
Chipping	Supplies
Gaging	

This cost ends when the castings are delivered to the shipping platform. Deliveries by truck to local customers, or to freight car, and freight and express out are chargeable to Account 192, Trucking, Freight and Express Out.

CLASSIFICATION OF ACCOUNTS

Method of Assigning Account Numbers

10 to 49	Regular Manufacturing departments
50 to 99	Auxiliary departments
110 to 189	General Overhead Expense accounts
200 to 299	Revenue accounts
300 to 399	Asset accounts
400 to 499	Liability accounts

In the Department Accounts, 10 to 99, the first numeral identifies the department, the second identifies the nature of the charge, as follows:

0	Direct Material
1	Direct Labor
2	Indirect Labor
3-1	Fuel
3-2	Sand and Materials
3-3	Miscellaneous Supplies and Tools

4 to 6 Reserved for special items
7 Repairs
8 Foremen and Clerks
9 Share of General Overhead—
9-1 Fixed Charges
9-2 Heat, Light and Power
9-3 General Expense

The following Standard Classification of Accounts, based on the cost divisions of the foundry as herein established, is recommended for use in gray iron foundries:

1. MELTING DEPARTMENT

10 *Metals:*

Pig iron
Iron or steel scrap
Alloys
(Including freight, cartage and unloading.)

12 *Labor:*

All labor in Melting Department, such as—

Transporting materials to charging floor
Hauling out slag and ashes
Charging
Patching
Cupola tending
Laboratory expense
Yard labor
Lining ladles
Relining cupola
Chemists
Cranemen

13-1 *Fuel:*

All melting fuel including freight, cartage and unloading.

13-3 *Miscellaneous Supplies and Tools:*

Flux
Fire-wood
Firebrick
Loam

Fireclay
Firesand
Coke forks
Waste

17 *Repairs:*

Labor and materials used for making repairs to all equipment in the Melting Department.

19 *Share of General Overhead:*

19-1 Fixed Charges
19-2 Heat, Light and Power
19-3 General Expense

2. MOLDING DEPARTMENT

SYSTEM A

(Procedure for Light Foundries)

21 *Molding Direct Labor:*

Molders
Apprentices
Helpers
(Includes pouring time if pouring is done by molders or helpers.)
Rammers
Finishers
Core setters

22 *Molding Indirect Labor:*

All other labor in the Molding Department, such as—

Pouring if done by separate pouring gangs
Cranemen
Board wheelers
Labor pouring and following heats
Shakeout labor
Flask fitters
Sand-reclaiming labor
Weight shifters
Mold-oven tenders
Pattern carriers
Tool-room labor
Gagger men
Sand-mill labor
Mold checkers
Dry-floor laborers
Sand cutter
Shank pusher
Facing-sand mixers

23-2 *Molding Sand:* (For Light Foundries)

Cost of molding sand including freight, cartage, and unloading.

23-3 *Miscellaneous Supplies and Tools:*

Plumbago
Brick
Fuel for dry-sand ovens
Fuel to dry pit molds
Nails
Bar iron and steel
Gaggers
Fire clay
Other compounds used in molding-sand mixtures
Facing
Sea coal
Lubricants
Waste
Air hose and fittings
Electric bulbs
Bolts
Clamps
Shovels
Riddles
Brushes
Lumber
Rammers and rammer butts
Tools
Parting

25 *Flasks:*

Labor and material used for making, altering, or repairing wood or iron flasks, bottom boards, plates, squeeze boards, bands, jackets, etc., which are not charged direct to customer. Whenever possible, the cost of special equipment should be charged direct to the customer.

26 *Patterns:*

All pattern-making labor and materials for making, altering or repairing patterns, mounting on boards, plates, etc., which are not charged direct to customer. Whenever possible, the cost of equipment should be charged direct to the customer.

27 *Repairs:*

Labor and materials used for making repairs to all equipment in the Molding Department (except flasks and patterns).

28 *Foremen and Clerks.*

29 *Share of General Overhead:*

29-1 Fixed Charges
29-2 Heat, Light and Power
29-3 General Expense

2. MOLDING DEPARTMENT

SYSTEM B

(Procedure for Heavy Foundries)

2 A—DISTRIBUTION ON DIRECT LABOR BASIS

21 *Molding Direct Labor:*

Molders
Apprentices
Helpers
(Includes pouring time if pouring is done by molders or helpers.)
Rammers
Finishers
Core Setters

22-2 *Molding Indirect Labor:*

All other labor in the Molding Department (except cranemen and sand shed labor), such as pouring, if done by separate pouring gang, delivering metal to floors, transporting castings, sprues, patterns, flasks, boards, bands, etc.

25 *Flasks:*

Labor and material used for making, altering, or repairing wood or iron flasks, bottom boards, plates, squeeze boards, bands, jackets, etc., which are not charged direct to customer. Whenever possible, the cost of special equipment should be charged direct to the customer.

26 *Patterns:*

All pattern-making labor and materials for making, altering or repairing patterns, mounting on boards, plates, etc., which are not charged direct to customer. Whenever possible, the cost of equipment should be charged direct to the customer.

28 *Foremen and Clerks.*

29 *Share of General Overhead:*

29-1 Fixed Charges
29-2A Heat and Light
29-3 General Expense

2 B—DISTRIBUTION ON TONNAGE BASIS

22-1 *Molding Indirect Labor:*

Cranemen
Sand shed labor

23-2 *Molding Sand:*

Cost of molding sand including freight, cartage, and unloading.

23-3 *Miscellaneous Supplies and Tools:*

Plumbago
Brick
Fuel for dry-sand ovens
Fuel to dry pit molds
Nails
Bar iron and steel
Gaggers
Silica flour
Molasses and glutrin
Fireclay
Flour
Dextrine
Other compounds used in molding sand mixtures
Facing
Sea coal
Lubricants
Waste
Air hose and fittings
Electric bulbs
Bolts
Clamps
Shovels
Riddles
Brushes
Lumber
Rammers and rammer butts
Tools
Parting

27 *Repairs:*

Labor and materials used for making repairs to all equipment in the Molding Department (except flasks and patterns).

29-2B *Power.*

3. CORE DEPARTMENT

31 *Core Direct Labor:*

Coremakers, apprentices, and other labor in the Core Department that can be specifically followed and charged direct to a job.

32 *Core Indirect Labor:*

All other labor in Core Department, such as—

Mixing core sand
Tending core oven
Cranemen
Transporting core sand, core boxes, and cores.

33-1 *Fuel:*

Cost of fuel for core ovens including freight, cartage, and unloading.

33-2A *Core Sand:*

Cost of core sand including freight, cartage, and unloading.

33-2B *Core Materials:*

Core oil
Flour
Molasses and glutrin
Core compound
Dextrine

33-3 *Miscellaneous Supplies and Tools:*

Nails
Bar iron and steel
Rods
Plates
Core wire
Fireclay
Bolts
Chaplets (when used excessively, charge direct to job)
Brushes
Air hose and fittings
Incandescent lamps
Lumber
Shovels
Riddles
Rammers and rammer butts
Tools

37 *Repairs:*

Labor and materials used for making repairs to all equipment in the Core Department.

38 *Foremen and Clerks.*

39 *Share of General Overhead:*

39-1 Fixed Charges
39-2 Heat, Light and Power
39-3 General Expense

4. CLEANING AND SHIPPING DEPARTMENT

(Simplified Method)

NOTE: The following is a simplified method for determining the costs in the Cleaning and Shipping department. The advanced method defined in the next section is recommended by the Institute Cost Committee as a method more adaptable to foundries wishing to secure direct, accurate cleaning and shipping costs on individual jobs.

42 *Cleaning, Finishing and Shipping Labor:*

All labor in Cleaning and Shipping Department, such as—

Tumbling
Sandblasting
Pickling
Digging out cores
Chipping
Grinding
Filing
Sorting
Inspecting
Gaging
Packing
Shipping
Weighing
Loading trucks
Welding
Moving castings
Clean-up labor

43 *Miscellaneous Supplies and Tools:*

Grinding wheels
Chisels and cutters
Blasting abrasives
Stars and jacks
Oxygen and acetylene
Welding torches and tips
Chipping hammers
Air hose and fittings
Blasting hose and nozzles
Bags and barrels
Crating lumber

47 *Repairs:*

Labor and materials used for making repairs to all equipment employed in Cleaning and Shipping Department.

48 *Foremen and Clerks.*

49 *Share of General Overhead:*

49-1 Fixed Charges
49-2 Heat, Light and Power
49-3 General Expense

4. CLEANING AND SHIPPING DEPARTMENT

(Advanced Method)

4-A—*Cleaning Department:*

NOTE: The following further subdivision of the Cleaning Department is made for the purpose of figuring a separate overhead percentage on Tumbling 4 AT, Sandblasting 4 AS, and Pickling 4 AP, since overhead items such as supplies, power, and depreciation of equipment may vary considerably on Sandblasting, Tumbling and Pickling. Each of these Departments would carry a complete set of accounts.

4-AT—*Tumbling Department:*

41-AT	Tumbling Direct Labor
42-AT	Indirect Labor
43-AT	Misc. Supplies and Tools
47-AT	Repairs
49-1-AT	Fixed Charges
49-2-AT	Heat, Light and Power
49-3-AT	General Expense

4-AS—*Sandblasting Department:*

41-AS	Sandblasting Direct Labor
41-AS-1	Mill Operators
41-AS-2	Hand Sandblast
41-AS-3	Table Sandblast
42-AS	Indirect Labor
43-AS	Misc. Supplies and Tools
47-AS	Repairs
49-1-AS	Fixed Charges
49-2-AS	Heat, Light and Power
49-3-AS	General Expense

4-AP—*Pickling Department:*

41-AP	Pickling Direct Labor
42-AP	Indirect Labor
43-AP	Misc. Supplies and Tools
47-AP	Repairs
49-1-AP	Fixed Charges
49-2-AP	Heat, Light and Power
49-3-AP	General Expense

4-B—*Finishing Department:*

41-B Finishing Direct Labor (grind, chip, file, gage, testing)
42-B Indirect Labor (sort, inspect, welding, moving castings)
43-B Misc. Supplies and Tools
47-B Repairs
49-B Share of General Overhead

4-C—*Shipping Department:*

42-C Labor, Packing, Shipping, Weighing, Loading
43-C-1 Barrels and containers.

NOTE: Whenever possible, the cost of containers should be charged direct to the customers.

43-C-3 Misc. Supplies and Tools
47-C Repairs
49-C Share of General Overhead

CLASSIFICATION OF ACCOUNTS IN AUXILIARY DEPARTMENTS

NOTE: It is entirely optional with each local foundry whether or not these Auxiliary Departments are used. They are shown here in detail only for the convenience of the foundries which may wish to use them. Their elimination will in no way interfere with the successful operation of this cost system.

5. CARPENTER SHOP

50 *Lumber.*
51 *Direct Labor.*
53 *Supplies and Tools.*
55 *Carpentry Work Purchased Outside.*
57 *Repairs.*
59 *Share of General Overhead:*

59-1 Fixed Charges
59-2 Heat, Light and Power
59-3 General Expense

6. PATTERN SHOP

60 *Direct Pattern Material.*
61 *Direct Labor.*

62 *Indirect Labor.*
63 *Supplies and Tools.*
65 *Pattern Work Purchased Outside.*
67 *Repairs.*
69 *Share of General Overhead:*
- 69-1 Fixed Charges
- 69-2 Heat, Light and Power
- 69-3 General Expense

7. MAINTENANCE DEPARTMENT

71 *Direct Labor.*
73 *Supplies and Tools.*
75 *Outside Work.*
77 *Repairs.*
79 *Share of General Overhead:*
- 79-1 Fixed Charges
- 79-2 Heat, Light and Power
- 79-3 General Expense

8. HEAT, LIGHT AND POWER DEPARTMENT

80 *Coal.*
82 *Labor.*
83 *Supplies and Tools.*
84 *Power and Light Purchased.*
87 *Repairs.*
89 *Share of General Overhead:*
- 89-1 Fixed Charges
- 89-2 Heat, Light and Power
- 89-3 General Expense

GENERAL OVERHEAD EXPENSES

1. FIXED CHARGES

110 *Taxes:*

Real, personal, and all other taxes except Federal and State income taxes.

111 *Insurance:*

All insurance for fire or property damage.

112 *Depreciation on Buildings.*
113 *Depreciation on Equipment.*

2. HEAT, LIGHT AND POWER

120 *Heat:*

Cost of all fuel, labor, supplies and tools, repairs and depreciation in boiler and engine room.

121 *Light and Power:*

Cost of all electric power, whether purchased or produced in local plant. If power is produced in private plant, cost of all fuel, labor, supplies and tools, repairs, and depreciation in the boiler and engine room.

3. GENERAL EXPENSE

Plant General Expense

130 *General Supervision:*

Superintendent, General Foremen, etc.

131 *General Labor:*

All miscellaneous labor which cannot be charged specifically to one of the manufacturing departments, such as—watchmen, janitors, and waste removal.

132 *Miscellaneous Plant General Expense.*

133 *General Repairs:*

Labor and material used for making repairs to buildings or equipment which cannot be charged specifically to one of the manufacturing departments.

134 *Workmen's Compensation Insurance.*

135 to 139 (Reserve for any special plant-general expense accounts desired.)

NOTE: If more than one plant is operated, accounts 130 to 139 would be divided into 130-A and 130-B, etc., to refer to plants A and B.

ADMINISTRATIVE EXPENSE

140 *Officers' Salaries.*

141 *Office Salaries:*

Accounting, Purchasing, Engineering Departments, Clerks and Stenographers.

142 *Miscellaneous General Expense:*

Office Supplies
Postage
Telephone
Telegraph
Directors' Fees
Dues
Subscriptions
Legal Expense
Auditing Expense
Traveling Expense, except Salesmen.

143 to 156 (Reserved for any analysis of miscellaneous general expense desired.)

157 *Interest on Mortgages or Bank Loans.*
158 *Loss from Bad Debts.*

Selling Expense

160 *Salesmen's Salaries, Commissions, or Bonuses.*
161 *Salesmen's Traveling Expenses.*
162 *Sales Office Salaries:*

Clerks or stenographers in Sales Department.

163 *Miscellaneous Sales Expense:*

Sales office expenses.

164 *Advertising.*
165 to 169 (Reserved for any analysis of Selling Expenses.)

GENERAL ACCOUNTS NOT INCLUDED IN FOUNDRY COSTS

Deductions from Sales

190 Defective Castings Returned
191 Allowances
192 Trucking, Freight and Express Out
193 Cash Discounts Allowed Customers

Revenue Accounts

Sales Accounts:

200 Castings
210 Patterns
220 Japanning
230 Machine Work and Assembling

Other Income:

250 Discounts Earned
251 Interest Received
252 Bad Debts Collected

Asset Accounts

Current Assets:

301 Petty Cash Fund
302 Cash in Bank
311 Accounts Receivable—Customers
312 Accounts Receivable—Sundry
315 Notes Receivable
321 Inventory—Raw Materials
322 Inventory—Finished Castings
327 Inventory—Foundry Supplies
331 Stocks and Bonds

Fixed Assets:

341 Land
342 Buildings
343 Machinery and Equipment
344 Tools and Equipment
347 Auto and Trucks
348 Furniture and Fixtures
349 Patterns

Prepaid Expenses:

361 Prepaid Insurance
362 Prepaid Interest
363 Customers Pattern Work

Liability Accounts

Current Liabilities:

411 Accounts Payable—Trade
412 Accounts Payable—Sundry
415 Notes Payable
421 Accrued Payroll
422 Accrued Interest
423 Accrued Liability Insurance
424 Accrued Taxes
429 Dividends Payable

Operating Reserves:

442 Depreciation on Buildings
443 Depreciation on Machinery
444 Depreciation on Tools and Equipment
447 Depreciation on Automobiles and Trucks

448 Depreciation on Furniture and Fixtures
449 Depreciation on Patterns
455 Reserve for Bad Debts
456 Federal Income Tax

Capital Accounts:

481 Capital Stock: Common
482 Unissued Stock
485 Capital Stock: Preferred
486 Unissued Stock
491 Capital Surplus
492 Earned Surplus
499 Profit and Loss Current Year

DISTRIBUTION OF GENERAL OVERHEAD

General Overhead

The entire General Overhead must be allocated to the four manufacturing departments and be completely absorbed by them, becoming a part of their department overheads.

Fixed Charges

The fixed charges are allocated to the four manufacturing departments at the beginning of the year. A fixed charge per month for each department is determined, and thereafter the same charge is used each month unless there are important changes in the building or equipment accounts.

Taxes, insurance, and depreciation should all be divided as nearly as possible in proportion to the value of the total investment in each department. This should always be done in the case of depreciation of equipment. Taxes, insurance and depreciation of buildings can often be apportioned with sufficient accuracy on the basis of floor space used.

Heat, Light and Power

This expense should be allocated in proportion to the actual or estimated consumption of power and heat in each department. A percentage for each department is determined at the beginning of the year, and thereafter this percentage is applied to the actual cost of power and heat for each month.

General Expense

The total general expense, including Plant, General, Administrative and Selling Expense, is allocated each month to the four manufacturing departments in proportion to the total payroll (direct and indirect) of each department.

NOTE: If Auxiliary Departments (such as Carpenter Shop, Pattern Shop, Maintenance Department, or Heat, Light and Power Department) are carried, or if any of the main departments are subdivided into sub-departments (such as 4 A, 4 B, etc.) the General Overhead is allocated to such Auxiliary or sub-departments in the same manner as described above for the four Manufacturing departments.

All general overhead has now been disposed of and becomes a part of the departmental overheads.

DISTRIBUTION OF DEPARTMENT OVERHEAD

1. MELTING DEPARTMENT

The entire cost of the Melting Department, the total of all accounts from 10 to 19, is combined into one total amount for the month. This total cost divided by the pounds of good castings produced, gives the cost of melted metal per pound of good castings produced, which can be applied directly to individual jobs on a pound basis.

NOTE: The cost of the metal at the spout is obtained by dividing the total cost of the Melting Department by the total pounds of good castings produced. If this average cost is applied to all jobs, light or heavy, there will be a slight inaccuracy due to the fact that for very light castings the weight of gates and sprues is a much larger proportion of the weight of good castings in the mold, than in the case of very heavy castings. We may have to melt 300 lbs. of metal to get 100 lbs. of good castings in one case, whereas in the other case we may only melt 120 lbs. of metal to get 100 lbs. of good castings. The extra metal is, of course, used over again so that the only additional cost is for fuel, labor, etc., used in melting.

In malleable and steel foundries, this is an important item and must be taken into account; but in gray iron foundries it is not so important. A gray iron foundry which produces all light work, or all heavy work, may use the same cost of melted

metal per pound of good castings produced for its entire output. Where both light and heavy work are produced, it is recommended that the cost of melted metal used for light work be slightly higher than the average, and for the heavy work slightly lower than the average. The correct figures for each should be determined by actual test.

2. MOLDING DEPARTMENT

(Procedure for Light Foundries)

The total of accounts from 22 to 29 gives the total molding overhead. This total divided by "molding direct labor" (account 21) gives molding overhead percentage. This percentage is applied to individual jobs on the basis of molding direct labor.

2. MOLDING DEPARTMENT

(Procedure for Heavy Foundries)

2 A—*Distribution on Direct Labor Basis*—

The total of accounts 22-2, 25, 26, 28, 29-1, 29-2A and 29-3 gives the molding overhead chargeable to individual jobs on a "Direct Labor" Basis. This total divided by "Molding Direct Labor" (account 21) gives the molding overhead percentage applicable to direct labor, and this is applied to individual jobs on the basis of direct molding labor.

2 B—*Distribution on Tonnage Basis*—

The total of accounts 22-1, 23, 27 and 29-2B gives the molding overhead chargeable to individual jobs on a "tonnage" basis. This total is divided by the pounds of good castings produced and gives the cost per pound, which is applied to individual jobs on a pound basis.

3. CORE DEPARTMENT

The total of all accounts from 32 to 39 gives the total core overhead. This total divided by "core direct labor" (account 31) gives core overhead percentage, and this is applied to individual jobs on the basis of core direct labor.

4. CLEANING AND SHIPPING DEPARTMENT

It is the practice in many foundries to carry the entire expense of the Cleaning and Shipping department in one

account and later prorate it either on a tonnage basis or as an overhead on direct molding labor. Both of these methods herein referred to as Alternative Methods for distributing cleaning and shipping costs have been accepted as satisfactory, as they are accurate enough for all practical purposes for about 80 or 90 per cent of the work in the average foundry. Any foundry may use either method (both of which are shown hereafter) which seems best suited to its particular class of work.

However, either of these alternative methods may lead to errors on special jobs requiring extra grinding, chipping, etc. It is, therefore, strongly recommended that all foundries carry the accounts in the Cleaning, Finishing and Shipping Departments as outlined herein as the "Advanced Method," so that they may be able to figure an accurate, direct Cleaning, Finishing and Shipping cost on any special jobs which may require it. Costs figured by either alternative method should be frequently checked by using the advanced method so that the foundry may determine how much of its work can be figured with sufficient accuracy by the alternative method, and how much must be figured by the advanced method in order to avoid serious profit leaks.

Direct Cleaning Costs

(Advanced Method)

Tumbling, Sandblasting or Pickling Costs are applied to individual jobs on a pound basis. However, when the foundry finds it necessary, direct cleaning costs may be determined in the manner provided for determining Finishing Costs, department 4 B. Sandblast cost may also be figured on a Sandblast hour basis.

4-AT—*Tumbling Department*

The total of accounts 41-AT to 49-AT divided by the total weight of good castings tumbled, gives the tumbling cost per pound.

4-AS—*Sandblasting Department*

The total of accounts 41-AS to 49-AS divided by the total weight of castings sandblasted, gives the sandblasting cost per pound.

4-AP—*Pickling Department*

The total of accounts 41-AP to 49-AP divided by total weight of castings pickled, gives pickling cost per pound.

4-B—*Finishing Department*

The total of accounts 42-B to 49-B gives the total finishing overhead. This total divided by "finishing direct labor" (account 41-B) gives the finishing overhead percentage. This percentage is applied to individual jobs on the basis of finishing direct labor.

4-C—*Shipping Department*

The total of accounts 42-C to 49-C divided by the total weight of good castings produced gives the shipping cost per pound. This cost is applied to individual jobs on a pound basis.

ALTERNATIVE METHODS FOR DETERMINING CLEANING COSTS

The total cost of the Cleaning and Shipping Department, the total of all accounts from 40 to 49, is combined into one total amount for the month.

Molding Labor Basis (Runge Method)

The total cleaning and shipping cost is divided by the total "Molding Direct Labor" (account 21) which gives the cleaning and shipping overhead percentage. This percentage is applied to individual jobs on molding direct labor basis.

Tonnage Basis (Klaus Method)

The total cleaning and shipping cost is divided by the total weight of good castings produced which gives the cleaning and shipping cost per pound. This cost is applied to individual jobs on a pound basis.

DISTRIBUTION OF DEPARTMENT OVERHEAD IN AUXILIARY DEPARTMENTS

The following covers the procedure when the auxiliary departments are used:

5. CARPENTER SHOP

The total of all accounts from 53 to 59 is divided by the time charged to Account 51, Direct Labor Carpenter Shop,

which gives the overhead percentage. This percentage is applied to individual jobs on the basis of direct Carpenter Labor. The total cost of each job is then charged either to a department Repair account (17, 27, etc.) to Flasks (25), or to General Repairs (133).

6. PATTERN SHOP

The total of all accounts from 62 to 69 is divided by the time charged to Account 61, Direct Labor Pattern Shop, which gives the overhead percentage. This percentage is applied to the individual jobs on the basis of direct pattern-making labor. The total cost of each job is then charged either direct to customer or to Patterns (26).

7. MAINTENANCE DEPARTMENT

The total of all accounts from 73 to 79 is divided by the time charged to Account 71, Direct Labor Maintenance Department, which gives the overhead percentage. This percentage is applied to individual jobs on the basis of direct repair labor. The total cost of each job is then charged either to a department repair account (17, 27, etc.) or to General Repairs (133).

8. HEAT, LIGHT AND POWER DEPARTMENT

The total of Accounts 80 to 89 is divided between and charged to Account 120, Heat, and Account 121, Light and Power, in proportion to the relative expenses thereof.

SCOPE OF THE STANDARD COST SYSTEM

It is not our intention and we do not believe it would be possible to design a system of cost accounting which would apply in every minor detail to every gray iron foundry in the United States and Canada. We do believe it is possible, and very desirable, that every gray iron foundry, in its cost accounting practice, should conform to the fundamental features of this Standard Cost System, which are as follows:

(1) The classification of departments and sub-departments, if sub-departments are used.

(2) The classification and definition of accounts. Every ordinary operation in the production of gray iron castings, and

every ordinary expense incidental to production has been classified and allocated to some definite account and department. In every department some accounts have been reserved for special items or further subdivisions when required. All gray iron foundries can observe these classifications. No item of overhead expense mentioned can be omitted if a true cost is to be obtained.

(3) Accurate timekeeping to get a correct distribution of direct labor to the individual job is essential in the Molding and Coremaking Departments. In the Cleaning and Finishing Department the necessity for direct labor timekeeping is left to the individual foundry to determnie.

(4) The method of distributing general and departmental overhead is a fundamental feature of this Standard Cost System. It is essential that all gray iron foundries should use the same uniform method of distributing overhead in arriving at cost figures used in quoting prices on prospective business. Only by this means can competition be on a sound, legitimate basis.

The above features are fundamental. In regard to the remaining details of purely accounting routine, we believe that it is advisable to leave them to the individual foundry to work out for itself. A good foundry executive should have, or should acquire, a working knowledge of the principles of cost accounting. A good foundry bookkeeper should be familiar with general accounting and cost accounting routine, and should be able to adapt this Standard Cost System to his own particular foundry. The Institute office will be pleased to further explain any features which are not clearly understood.

The maximum benefit will be obtained, however, by securing the assistance of some consulting foundry cost accountant who is thoroughly familiar with the Standard Cost System, and who has had actual experience operating it in other gray iron foundries. If you do not know of such an accountant locally, the Institute office will be glad to place you in contact with a capable and experienced foundry cost accountant.

Accounting for Labor

The method of collecting labor data for the cost-accounting records is very important. Unless it is performed with accuracy and ease the results are unreliable and misleading. Since the cost of individual castings is dependent largely on correct labor

costs, it is evident that incorrect labor data may lead to disastrous cost figures. The labor data for the various accounts given in the Standard Classification of Cost Accounts are obtained from the records used for distributing the time, that is, the classification of labor according to the nature of the work. Data for employees on a salary basis are obtained from the salary payroll.

Accounting for Materials, Supplies and Other Charges

Data pertaining to the cost of materials, supplies and other charges are obtained from heat reports, monthly inventories, stores' requisitions, voucher records, reserve accounts in the cost ledger, etc. It is important that these charges be correctly classified and applied to the proper cost accounts.

Inventories

Monthly inventories must be taken in order that a monthly profit and loss statement can be obtained.

Good Castings Produced

The weight of good castings produced is obtained by adding to the weight of good castings on hand at the end of the month the weight of castings shipped during the month and deducting the weight of good castings on hand at the beginning of the month.

Shop Scrap

A careful record of all castings scrapped before shipment should be kept, in order to keep this loss down to a minimum. No account number is provided for shop scrap, since tonnage costs are figured on the basis of *good* castings produced. If scrap losses increase, the amount of good castings produced will be less, and tonnage costs will be increased.

Defective Castings Returned

The cost of defective castings returned by customers is charged to Account 190, Deductions from Sales-Defective Castings Returned, and is not included in general overhead. After the cost of any individual job has been arrived at by using normal direct and overhead rates, a percentage should be added to cover the actual loss in that particular job, as near as it can be estimated or determined.

If the cost of all "Defective Castings Returned" was in-

cluded in General Expense, this cost would be spread evenly over all jobs, whether the actual loss was 5 per cent or 20 per cent. It is, therefore, more equitable for each job to stand the actual loss thereon, as above recommended.

Trucking, Freight and Express Out

Complete cost figures determined by this cost system, including an estimated percentage for profits and loss, represent the cost f. o. b. foundry. When delivery is made from the shipping platform to local customers or to freight cars, the delivery charge must be added to get the total cost. Deliveries by the company's trucks should be determined as accurately as possible on a cost per pound basis for various destinations, local or distant. If shipped by freight or express the particular job should be charged with the actual shipping costs.

Depreciation

Depreciation of plant and equipment must be charged into current costs of production, as it is an item of expense. The need of charging depreciation to current costs arises from the fact that working assets gradually give out or become obsolete. In other words, they are used up in production, and the cost of this usage or consumption is part of the cost of the product being manufactured.

The test for determining the percentage of depreciation is the estimated life of the equipment. Buildings are subjected to similar depreciation, but the estimated life is usually much longer.

This charge to costs for depreciation cannot be abandoned simply because profits are non-existent, for depreciation accrues whether or not there is a dollar of profit. It is preferable that depreciation be accumulated in a depreciation reserve account, charging costs of production each month and crediting the depreciation reserve account in the ledger. This reserve is directly affected when renewals are made and when the property is exchanged, sold, replaced, or abandoned.

> NOTE: There is no authentic schedule of depreciation for gray iron foundries available. However, the Institute office has on file certain information on this subject which may be of service to you. When requesting same, please state specifically the information desired.

Interest on Investment

It is the practice in many foundries to carry the interest on investment (at a rate of 6 per cent annually) as an item of overhead expense. This practice is general in many sections of the country. We believe that interest is a legitimate item of costs and should be included therein—just as rent, when incurred, is a proper charge to costs. It should be noted, however, that in preparing income tax returns, interest on investment is not an allowable deduction.

Capital and Revenue Expenditures

When new equipment is purchased, and when old equipment is replaced, major items are charged to capital accounts and a percentage for depreciation is charged into costs each month. In the purchase of minor items, such as small tools, etc., the whole cost is charged directly to expense in the month in which the purchase was made. In doubtful cases, the safest policy is to charge the whole cost directly to expense.

Operating Reserves

Operating Reserves measure the cost of operations which, while not necessarily expended at the time, will positively be incurred according to past experience. The following reserve accounts are recommended:

Reserved for Depreciation:

A definite amount is charged each month to manufacturing costs, under General Overhead, Accounts 112 and 113, and the same amount is credited to the "Reserve for Depreciation" account in the ledger. (Note the paragraph on Depreciation.)

Reserved for Doubtful Accounts:

A definite percentage of total casting sales or a definite amount per ton of good castings, is charged to costs each month in account 158, "Loss from Bad Debts," and the same amount is credited to the reserve account in the ledger. As bad debts occur they are charged to the reserve account in the ledger.

In addition to the above, which represent the major items to be handled as reserves, others such as the following may be taken care of in the same manner:

Reserved for Cupola Relining
Reserved for Flasks
Reserved for Loss of Defective Castings After Shipment
Reserved for Inventory Adjustments
Reserved for Taxes and Insurance

Normal Overheads

It is quite apparent that in a foundry which normally produces 200 tons per month, the Fixed Charges and General Expense will remain about the same whether production is 100 tons per month or 300 tons per month. Naturally, when production is low, the actual overhead percentages will be higher than when the production is high.

In estimating work, it is generally the standard practice to use so-called "normal overhead" percentages, that is, overhead percentages arrived at by using the cost figures of a normal year. Ordinarily the actual overhead percentages for the previous year are used, unless it was an abnormal year. Normal production for establishing normal overhead percentages is generally considered to be about 70 per cent of capacity. In estimating, the same "normal overhead" percentages are ordinarily used without change throughout the year, any necessary adjustment being made at the end of the year.

Cost of Individual Castings

The old method of quoting flat prices or a schedule of prices by weight usually works out to the disadvantage of the foundry. Many foundries are refusing to quote flat prices. We strongly recommend that, whenever possible, foundries insist on quoting individual pattern prices per pound or per piece.

In some cases average prices can be quoted on a machine, or class of machines, but if so, individual pattern costs should be figured on all castings required for the machine, and these costs averaged. Such average prices should only apply if the customer orders the complete list of parts specified in his inquiry.

Profit

The astounding percentage of business failures clearly shows the necessity for establishing selling prices which not only cover the complete cost of doing business, but also include sufficient profit to enable the company to perpetuate itself and make new improvements. A company can be permanently successful only

when the element of profit is given careful consideration before selling prices are established.

It is necessary, when making quotations, to include an amount of profit sufficient to insure returns which will be large enough to assist in payment of dividends during periods of business depression which occur from time to time.

It is also very necessary, when establishing selling prices, to include an amount of profit in addition to that required for dividends during periods of depressed business, sufficient to provide for a consistent development of the business and for the maintenance of surplus reserves. This is a fundamental economic principle upon which the permanent success of any industry must be based. This principle is often disregarded to the detriment of the entire industry.

DISCUSSION

ORAL DISCUSSION

CHAIRMAN A. E. HAGEBOECK:* We have had considerable discussion on costs at our past meetings, and our committee has gone on from year to year featuring the use of uniform systems of cost accounting. We feel now that real, definite progress is being made.

We have cooperated with the steel branch of our industry with excellent results. It will be recalled that at our 1925 Philadelphia meeting there was presented for discussion a cost system for steel foundries recommended as a standard by the Steel Founders' Society of America, and our committee recommended its use in all steel foundries.

The Malleable Iron Research Institute also has a standard system which the A. F. A. committee has recommended for use in all malleable iron foundries.

In addition, we now have a recommended standard for gray iron foundries, formulated by the Gray Iron Institute. This standard will be presented by J. L. Carter.

In each case, these systems originate with the particular branch which is most interested. We feel that our A. F. A. committee very properly can act as a clearing house to assist these branches when they wish to attack any particular problem having a national aspect.

The nonferrous group has not made quite the progress that some of the others have, but I believe we are making satisfactory progress. I think we have made more progress in the nonferrous branch of the

*Frank Foundries Corp., Moline, Ill.

industry during the past two years, in the way of standardized, uniform and cooperative methods, than was made for many years prior to 1928.

J. L. CARTER: *The preparation and publication by the Gray Iron Institute of a standard cost system for gray iron foundries is an event of the utmost importance to the whole gray iron industry. In presenting it, I shall read some parts of the introduction and then endeavor to give a brief description of the main features of the system itself, outlining briefly the future cost program of the Gray Iron Institute.

(Mr. Carter then referred to the Summary of Advantages of Good Cost-Accounting Practice, as given in the Institute Cost System. See pages 577-579.)

The advantages of a standard cost system, it will be noted, have been divided into three parts, as follows:

1.—The advantages to the individual foundry of any good cost accounting system.

2.—The advantages to the industry of a standard cost system.

3.—The advantages to the industry of uniformity in cost-accounting practice.

Advantages to Individual Foundries

The advantages in the first division would influence one to install a good cost-accounting system, but they would not be a conclusive argument for adopting any one particular method. There are many ways to figure costs, and many different methods are in actual use among gray iron foundries. The accountants who install them can often —but not always—advance good reasons in support of some pet feature of their systems.

If we were operating a foundry on the island of Hawaii with no competition at all, or if the demand for castings in this country exceeded the supply to such an extent that our selling prices were not seriously affected by competition, we still would need a cost system to run our business intelligently. However, we could choose any system and it would make very little difference to us whether our competitors used the same or some other system.

Under the keen competitive conditions which exist today in our industry, our selling prices are determined to a great extent by those of our competitors. Our cost system will tell us that we can take a certain job at seven cents per pound and make a reasonable profit, but if one of our competitors figures his costs by a different method and arrives at a selling price of six cents per pound, he is likely to take the job away from us.

If our foundry is very efficient, so that our costs are below the average, we should get most of the business we figure on, at fair prices.

*Chairman of Cost Committee, Gray Iron Institute, and Vice-President and General Manager, Sacks-Barlow Foundries, Inc., Newark, N. J.

A few more efficient foundries could beat us legitimately, but most of our competitors could not quote lower prices if they figured their costs correctly. Let us say that 50 per cent of the business we lose is due to our competitors actually producing at lower cost, while 50 per cent is due to our competitors' lack of correct cost-accounting methods.

If this is so, it is very much to the interest of foundrymen to induce their competitors to adopt a good cost system. However, our competitor may think he has the best cost-accounting system possible, and, because he devised it himself, we can never persuade him to adopt our method. Nor will he ever be able to persuade us to adopt his method.

The deadlock can only be broken by both parties agreeing to allow some respected neutral cost expert to devise a uniform system which will embody the best features of both systems, which both foundries then will adopt.

When several foundries are considering the formation of a local cost group, their first problem is to find some uniform cost system which has sufficient prestige in the trade so that all members of the group will be willing to adopt it. Up to the present time no such standard system has been available. I know from personal experience that the lack of such a standard system for gray iron foundries has held up the formation of cost groups in several foundry centers.

The Gray Iron Institute, therefore, has made a valuable contribution to the gray iron industry by providing it with a standard cost system, devised by practical foundry executives and experienced foundry cost experts, and backed by a national trade association.

Advantages of Standard Cost System

The second group of advantages includes those which the industry obtains from the fact that such a standard system has been developed, published, recognized as standard and is available for any foundry or group of foundries who wish to make use of it.

Advantages of Uniform Cost Practice

The third and most important series of advantages will not be obtained until a large proportion of gray iron foundries actually have adopted this standard cost system and are using it in figuring costs and selling prices. We have a definite program for promoting its use, but our success will depend entirely on the cooperation we receive from gray iron foundry executives.

The advantages of uniform cost-accounting practice to any industry are so great and so generally recognized that we feel our cost program should have the support of every gray iron foundryman. Our program can be helped considerably by each foundryman adopting this system at once in his own plant. Every foundry that adopts it makes it easier for us to persuade other foundries to do so. The best possible way to recommend it to others is to tell them that others are using it and have found it very satisfactory. We will welcome and reply to any constructive criticism, and will make a record of it for future use.

On behalf of the Gray Iron Institute, I wish to express our appreciа-

tion of the cooperation we have received from the American Foundrymen's Association in giving us this opportunity to bring our standard cost system to the attention of its members.

Outline of Standard Cost System

I shall now outline briefly the main features of the Gray Iron Institute's cost system. In its simplest form, it is designed to meet the needs of small foundries which desire the least possible clerical expense. It is, however, capable of expansion by further subdivision of products, departments and accounts, so as to give any amount of detailed information. In this paper I shall describe only the simplest form.

In the simplest form of this cost system, the foundry is divided into four main departments, as follows:

1.—Melting.
2.—Molding.
3.—Core Making.
4.—Cleaning and shipping.

In addition to the cost of operating these manufacturing departments, there is, of course, a certain amount of general overhead expense which cannot be charged directly to any one of these four departments. This general expense includes such items as the following:

Fixed Charges—
Taxes, insurance and depreciation.

Heat, Light and Power.

General Expense.

Plant General—
General superintendent, general labor, etc.
General repairs, compensation, insurance, etc.

Administration Expense—
Officers' salaries, office salaries, office expenses.
Interest on mortgages and bank loans, losses from bad debts, etc.

Selling Expense—
Selling salaries, expenses and advertising.

This entire general overhead is first allocated to the four manufacturing departments and is completely absorbed by them, becoming a part of their departmental overhead.

Taxes, insurance and depreciation are allocated on the basis of the value of the buildings and equipment used by each department. This is calculated at the beginning of the year, and thereafter the charge for each department is exactly the same each month.

Heat, light and power are allocated on the basis of the actual consumption by each department. The percentage used by each department is estimated at the beginning of the year, by listing the horsepower of motors and hours operated. This percentage, applied to the total power bill for any one month, gives the power charge for that month.

All the rest of the general overhead—administration, selling and plant general expense—is allocated in proportion to the total payroll, direct plus indirect, of each department. When the general overhead has been allocated in this manner, there remain just the accounts in the four departments.

In each of the four departments—Melting, Molding, Core Making, and Cleaning and Shipping—there is a list of departmental accounts. They will vary somewhat. Of course, the Core Department setup will be very similar to the Molding Department. In the Melting Department there is only one labor account—no direct labor; it is all indirect. In the Cleaning and Shipping Department, if the simplest method be used, there will be only one labor account there also, into which all labor is dumped.

Each department, it will be noticed, has an account called Share of General Overhead, so that each of these four departments has, as a part of its departmental overhead, its proper share of the general overhead. Thus, there is no more general overhead with which to bother.

All General Overhead has now been allocated, leaving only departmental overheads to deal with, which include their proper share of the General Overhead.

(Mr. Carter then referred to the sample list of accounts for the Molding Department, as given in the Institute Cost System. See pages 584-587.)

We must now distribute the total departmental costs to individual jobs. This can best be explained by referring to the text of the Institute Cost System.

(Mr. Carter then referred, in the Institute Cost System, to the following sections: Distribution of Department Overhead for (1) Melting Department, (2) Molding Department—Procedure for Light Foundries, (3) Core Department, (4) Cleaning and Shipping Department; also (5) Alternative Methods for Determining Cleaning Costs. See, respectively, pages 597, 598, 598, 598, 600.)

Let us assume that the cost-accounting records of an ordinary light-work jobbing foundry have been kept for a sufficient period to determine overhead percentages, etc., and that these figure out as follows:

Cost of melted metal, per lb. of good castings produced	1.5c
Molding overhead, per cent	100.0
Core overhead, per cent	100.0
Cleaning and shipping cost, per lb. (tonnage basis)	1.0c

The above figures apply to all jobs. In order to figure the cost of any individual job, we must also estimate or determine from records of this particular job, the percentage of loss from defective castings scrapped before shipment, plus those returned defective from customers. This might vary from five per cent on some plain jobs, to 20 per cent on difficult jobs.

We must also determine the cost of delivery. This might vary from zero for castings picked up by customers' trucks to one-half cent or more per lb. for castings shipped to distant points by truck or freight.

It will be noted that these two accounts—Cost of Delivery and Cost of Defective Castings—are not included in the regular cost accounts. They are handled as Deductions from Sales, and the proper charges for each individual job are added as separate items to its cost. This is because there is such a wide variation in these items, and their cost on any job can easily be determined or estimated.

We must also estimate, or determine from records, the weight, the

Table 2

METHOD OF FIGURING COST OF JOB

	Cost per lb., cents.
Cost of melted metal	1.5
Molding direct*	1.0
Molding overhead, at 100%	1.0
Core direct	0.5
Core overhead, at 100%	0.5
Cleaning and shipping*	0.5
TOTAL	5.0
Percentage of loss, at 10%	0.5
Cost, f. o. b. foundry	5.5
Delivery cost	0 2
TOTAL COST	5.7

*Runge method: Cleaning and Shipping Overhead equals 50 per cent of Molding Direct.

cost of direct molding labor and the cost of direct core labor. Let us assume the following figures:

Weight, lbs	10.0
Direct molding, per lb	1.0c
Direct core making, per lb	0.5c
Loss, per cent	10.0
Delivery cost, per 100 lbs	20.0c

The cost on this job would then be figured as shown in Table 2.

CLEANING AND SHIPPING COST

The most serious chance for error in this cost figure is in the item for cleaning and shipping—1c per lb. If the tonnage basis is used, this average figure of, say, 1c per lb. would be applied to all jobs, whereas the actual cost of cleaning and shipping might vary from less than ½c to over 2c per lb.

The only way to figure cleaning and shipping cost accurately is to use the direct method, but most foundries are not willing to go to the extra trouble and expense of figuring direct cleaning costs. In order to do so, the Cleaning and Shipping Department must be divided into three parts, as follows:

1.—Cleaning—
Tumbling, sandblasting, pickling.

2.—Finishing—
Grinding, chipping, filing, etc.

3.—Shipping—
Packing, weighing, loading, trucks, etc.

A separate cost per pound is determined for tumbling, sandblasting and pickling. The cost of sandblasting, which usually is higher than the cost of tumbling, would only be applied against castings which are sandblasted. The cost of shipping would be figured separately on a per-pound basis, which could be used for all jobs without serious error.

The cost of finishing, however, varies greatly. Some plain heavy work might be ground for less than one-fourth cent per pound. Other light cored jobs, where fins cannot be avoided and where the customer requires a very fine finish, might cost over two cents per pound to grind or file. The only way to get this cost accurately is to clock the actual direct finishing labor and add a Finishing Department Overhead.

The Cost Committee realized that the only method they could recommend as theoretically accurate was Direct Cleaning Cost. They also realized that 90 per cent of the foundries, at the present time, would refuse to use this method, as it would mean that a time clerk would have to take up the time spent on each job by every grinder, chipper or filer.

Accordingly, we have recommended Direct Cleaning Cost as the only theoretically accurate method, but have accepted two simpler approximate methods as satisfactory for the ordinary jobbing foundry.

In the Tonnage Basis method advocated by Chas. A. Klaus, the average cost of cleaning and shipping per pound is applied to all jobs. In the Molding Labor Basis method advocated by E. T. Runge, the total cost of cleaning and shipping, divided by the total molding direct labor, gives a cleaning overhead percentage which is applied to individual jobs on the basis of direct molding labor.

If a foundry manufactures only one type of casting, either of these approximate methods would be entirely satisfactory. For the average jobbing foundry they are accurate enough, for all practical purposes, for about 80 to 90 per cent of the work. However, in every jobbing foundry some of the work will cost less than the average figure used, and some will cost more. The error will be serious on at least 10 per cent of their jobs. In order to locate these errors, we have suggested a simple plan which involves practically no additional clerical expense.

It is a comparatively simple matter to analyze the payroll and

carry separate accounts for Tumbling Labor, Sandblasting Labor, Finishing Labor (grinding, chipping and filing in one account), and Shipping Department Labor. From these figures a separate cost per pound can be determined for tumbling, sandblasting and shipping. There is also the total of finishing labor direct, and when all other costs of the Finishing Department are divided by this finishing direct labor, a Finishing Overhead percentage is obtained.

These figures can be obtained without using any job tickets for the grinders and chippers, which is the difficult and expensive part of direct cleaning costs. Nevertheless, with these figures, a direct cleaning cost can be figured on any individual job merely by clocking the grinding or chipping or filing time on that particular job, which would not require more than fifteen minutes of a clerk's time.

Then the approximate method ordinarily can be used, keeping on the lookout for jobs which require an abnormal amount of grinding, etc., and figuring an accurate direct cleaning cost on those.

This question of cleaning cost has not been given the attention it deserves by foundrymen. Unless a foundryman is one of that small number using direct cleaning costs, it will pay him to investigate his cleaning costs by the simple plan suggested. I venture to state that serious profit leaks will be discovered, where fussy jobs have been actually costing from one cent to two cents per pound more to clean than the average amount included for cleaning cost.

(Mr. Carter then referred to (1) Scope of the Standard Cost System, and (2) Normal Overheads, in the Institute Cost System. See, respectively, pages 601, 606.)

CHAIRMAN A. E. HAGEBOECK: This cost system represents the work of many years. The Gray Iron Institute, in working out this standard system, has tried to get advice and counsel from those men who have been devoting much time and thought to cost methods in gray iron foundries.

MEMBER: How is the allocation of overhead to departments made? Is it on the basis of area of the whole shop proportionately—molding, core room, cupola and cleaning room?

J. L. CARTER: The general overhead consists of three parts. One is what I have called fixed charges—taxes, depreciation and insurance. Then there is heat, light and power, and there also is general expense, which includes administrative and selling. The overheads are allocated to the four departments by different methods.

The fixed charges—taxes, insurance and depreciation—are the only ones allocated on the basis of something like floor space. They can be allocated on the basis of floor space, but we advocate that they be allocated on the basis of the actual value of the equipment in the department.

For instance, in the melting department, the fixed charges are applied to the value of the building and the value of the equipment used by the melting department. The same is true with the molding department and the other departments.

Heat, light and power are divided according to the power actually consumed by each of the four departments. These are very fair methods.

As to the general expense, possibly a somewhat more arbitrary method of distribution is used. General expense is distributed in proportion to the total payroll direct, plus indirect, of each of the four departments.

MEMBER: What objections are there to allocating fixed charges to cost of metal instead of to departments?

J. L. CARTER: There are very grave objections to that procedure. If fixed charges are charged to the cost of metal, it would be almost like allocating it altogether to the melting department.

For instance, if one foundry has a large core room and another foundry has practically no core work, the foundry with the core room would have to have additional buildings and additional equipment in order to make the cores. That additional department ought to be charged with its proper share of the general overhead, which should then go into the core costs.

If it were not done in this manner, a sufficient additional charge for the making of the cores would not be made. It seems to me that dividing the business into four parts, as outlined in this cost system, and then dividing general overhead as fairly as possible between the four departments, is a natural way to do it. If there is any reason or argument for the other method, I should be glad to hear it.

E. T. RUNGE:* Originally, the cost of castings was figured at so much per pound. That method was found to be wrong. If it was found to be wrong as a means for figuring total costs, is it not wrong also for only a part? Therefore, the pound average cost, except for melting, is ancient history and has practically gone by the boards.

ROBERT E. BELT:† The distribution of the entire overhead on the basis of tonnage is wrong. It does not give the dependable results one needs in cost work. There is a part of the overhead, however, that does go with tonnage.

The overhead that is applicable to the melting department, for example, I believe is properly distributable on the basis of weight. However, the overhead which applies particularly to molding, core making and cleaning is not directly related to weight and should not be so distributed.

CHAIRMAN A. E. HAGEBOECK: If I understand the theory on this cost system, it is that each department bears its total cost. For example, take the core department and look at it as though it were a separate plant across the street.

That building would have to be rented, or else the ground on which it is built would have to be purchased. Having that department across the street, all of the costs could be allocated very easily. That would be simply a business all by itself—a core-making business—and all of the

*E. T. Runge Cost Co., Cleveland.
†Malleable Iron Research Institute, Cleveland.

costs pertaining to operating that building would have to go into the cost of the cores.

The same thing applies to the melting department. That department should be considered as a unit all by itself, and it should bear all of its costs, including general overhead. The same thing is true with the molding department, and also with cleaning and shipping. Therefore, if all these departments are to be treated separately, certainly they should all bear a portion of the general overhead expense.

In regard to the matter of heat, light and power, the method recommended by the Institute is to charge the departments in proportion to the power, light and heat actually consumed by each. General expense is distributed on the basis of total payroll, both direct and indirect.

MEMBER: In considering the distribution of indirect labor on the direct labor basis, how would that apply in the case of a molder who, instead of making 150 molds, made 75 molds, the slowing down in production being no fault of his but due to the characteristics of the job? In that case, would you say that, in reality, he incurred the same overhead as if he had made 150 molds, and would you distribute it on that basis?

J. L. CARTER: In making up any cost system—a system to be used for all jobs—it is necessary to use some one definite method. It is true, if the job is given to a molder who produces it for half the direct labor cost for which another molder would produce it, that only half the overhead is applied to it.

However, in arriving at any costs to be used in making prices, the management of the foundry has to be sure it is using a sound direct labor cost. In other words, a direct labor cost should be used which one can reasonably expect to obtain from a good molder.

This means, of course, that it should be used in making selling prices. The variation between one molder and another should not affect the cost used in estimating. It should be merely a matter for the attention of the management.

MEMBER: What would be wrong, in this case, with putting the molding on a machine-hour basis? On that basis, molding would take the same amount of overhead per hour whether the molder made 50 or 100 molds. The same amount of overhead would be charged against each molding machine, or against each molder, which would not be true in the case of the direct labor basis.

J. L. CARTER: Are you referring to the comparison between hand molding and machine molding, or between two machine molders of different ability?

MEMBER: Let us say that there are three kinds of molders in the same building—machine, bench and core molders. Of course, the machine molders would be put on a machine-hour basis, but if this principle be carried all the way through, then the overhead would not be charged against the work as it should be.

J. L. CARTER: I do not know that I understand fully, but I believe the point I made previously is the chief one: Determine what a reasonable direct charge is, and use that as a basis.

ROBERT E. BELT: I am not so sure we have in mind the same method of distribution and the same character of overhead. Consider, for instance, two molders on the same pattern, working side by side. The man on the machine gets up to 200 molds a day, the bench molder to 100 molds a day, and they are both earning, say, the same daily wage. In such a case, on a molding direct labor basis, the overhead would be distributed in amount equally, but one molder would have twice the production of the other, which would give, for both direct labor and overhead, units that would be widely different.

J. L. CARTER: I believe this problem is covered by the notation in the Institute Cost System covering possible subdivisions of main departments, reading as follows:

> "Any of the four main departments may be subdivided into as many classifications or divisions as desired. The following subdivisions are only suggested, as their use is entirely optional with the local foundry.
>
> "In the Molding Department it is suggested that it might be advisable to divide this into: *2-a* Heavy Floor; *2-b* Light Floor (not under crane); *2-c* Bench; *2-d* Squeezer Machines; *2-e* Jolt Machines."

If the foundry has a squeezer department and a bench department in which the molders are performing time work on a lot of miscellaneous loose work, certainly the direct labor cost is going to be much lower on the squeezer machine. The only way in which the cost can be fairly determined is to divide the molding department into separate departments.

Then a separate overhead must be used for the squeezer department, and it should be fairly accurate. The overhead in the bench time-work division will be much lower than in the squeezer division, because in the latter the direct labor cost is less and, therefore, the overhead is higher.

ROBERT E. BELT: Of course, in many foundries, both gray iron and malleable, it is hardly practicable to separate different types of molding. Where a separation is not practicable, a portion of the overhead can be distributed on the basis of weight and a portion on the basis of labor, thus obtaining a reasonably accurate distribution of the overhead as applying to different types of molding.

Nevertheless, wherever the operations warrant it, there should be a strict separation between different types of molding, particularly machine molding and bench molding. Any attempt to distribute overhead on both machine production and bench production, on the same basis, will result in costs which are hardly dependable.

J. L. CARTER: In devising this system we have had in mind the small foundry and the large number of foundries having very little knowledge of costs, or very little in the way of a cost system at the present time. It is absolutely necessary, in order to get a system that foundries will use, to make it simple and to use the simplest method that will serve the purpose.

Thus, in the simplest form of our system, we have held to that principle and have left it to the option of the individual foundry to further subdivide and get more detailed information if they think it necessary, but still observing the same general principle.

M. M. MARCUS:* We have made a comparison of these costs which proves their accuracy. We distribute our overhead or figure our overhead to a molder's floor; all of these various costs are placed on the molder's floor. We took these costs and compared them with two distinct jobs, one of light work and one of heavy work; one on which the molder would produce 400 lbs. a day and one on which the molder would produce 1500 lbs. a day.

Based on these costs we found that, under the system method of figuring, on the 400-lb. job our cost would be 7.15c per lb. By our own method of figuring, that is, by distributing our costs to the molder's floor, the cost would be 7.25c—a difference of only 0.10c per lb.

Then we compared the 1500-lb. job and found that, since we have to figure our 50 per cent overhead on the cleaning cost when we use a greater tonnage, it would total 4c, as compared with 4.05c with the system. Therefore, I feel that this system is very accurate.

In detail, the figures, by the Institute system method, are these: Figuring the metal at 1.5c, that is, on the 400-lb. basis, and the molding cost at $8.00 a day for one molder—which is the average wage for a good mechanic—the cost is 2c per lb. for molding; overhead (100 per cent) is 2c per lb.; cleaning, 1c per lb. In this case that is all there is to figure, because there are only 400 lbs. of metal. Figuring cleaning and shipping as 1c per lb., this gives a total of 6.5c, and a 10 per cent loss will bring the basic cost to 7.15c.

Our way of figuring would be as follows: $8.00 for the molder; 400 lbs. of metal at 1.5c or $6.00, and overhead per molder floor per day at $15.00—a total of $29.00. This amount, divided by 400, gives 7.25c per lb. basic cost, which is very close to the 7.15c arrived at under the system method.

Using 1500 lbs. of metal, we figure the molder makes about $8.25—we are paying 5.5c per mold. At 1.5c, the metal cost is $22.50, and normal overhead is $15.00, plus 1c additional overhead for handling. This gives a total of $60.75, and dividing that figure by the 1500 lbs. gives just about the same result as was obtained under the system method—4c plus.

CHAIRMAN A. E. HAGEBOECK: The point Mr. Marcus brings out very clearly is that whenever he has a job, he adds a little more for cleaning if necessary—as on this particular job—but that any job having a large portion of special work in the foundry should be scrutinized closely.

One good way to catch such jobs is to check up their average cost of molding per 100 lbs. of good castings. If the factory has a molding cost of 60c per hundred, and one job is found which costs only 30c a hundred to mold, that is a good job to look into, to see whether the method of applying overhead is correct. On the other hand, if the

*Spring City Foundry, Spring City, Pa.

average is 60c a hundred and one job is costing 1.5c per lb. to mold, that job should be scrutinized carefully.

The discussion has brought out the point we wished to emphasize, that this recommended standard system is not a cure-all for all foundries and all jobs, but a basic principle; and that, where special jobs occur, they must be given special attention.

M. M. MARCUS: We have cases where we only get about one and one-half pounds to a mold and we have to grind the work. A charge of 2.5c is made for grinding.

MEMBER: Mr. Carter, why is 10 per cent loss added on the whole 7.5 cents? The metal has not been lost. Of course, the cost of melting it has been lost—the labor in melting it and the overhead—but the iron is still there. It is in two stages, some in the cleaning room, where it is found to be deficient, and also a certain percentage which comes back having already been cleaned.

I was much interested in the discussion on the allocation of the cleaning cost. I am thinking now of the jobbing foundry, running various classes of work, some requiring sand-blasting.

For instance, to clean a jig might take a man a great deal of time, if it is an intricate one, and it might not weigh very much. On the other hand, there is what we call the "flat back," which the cleaners can work on with a hammer. If we should approach this thing in detail, we would have to have a clerk standing by with an infinite number of time costs, and I am afraid that would add some more to our overhead.

In the jobbing foundry business, regardless of how we would like to price every casting, we still are up against the flat cost. We must be careful to charge in sufficient overhead in order to take care of cored and non-cored, because we cannot pick our jobs to suit ourselves.

J. L. CARTER: The only error in adding the 10 per cent loss, so far as I can see, is that the scrap value of the castings is not taken into account. In other words, too large a per cent is given for the loss, considering the scrap value of the metal, and that is all. A small part of the cleaning cost might be saved if the casting is thrown out before it goes through the cleaning operation, but certainly it is safer to add enough to protect one's self, rather than too little.

What basis would you recommend? What basis would you prefer?

MEMBER: We know the cost of the metal direct. I should eliminate that. In other words, I would take the 10 per cent loss and then deduct the scrap value.

J. L. CARTER: That is a perfectly legitimate way to handle the loss. There is nothing wrong with your method.

A. T. BOOTH:* In figuring the loss, 10 per cent of 7.5c, or ¾c, is given. Does not that 7.5c represent only 90 per cent of the cost?

J. L. CARTER: Unless we are going to use higher mathematics, we must use the cost that we have arrived at first before we can add a percentage to it.

*Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

A. T. BOOTH: But the cost is 7.5c before the loss is added. To my way of thinking, that is only 90 per cent of the cost.

J. L. CARTER: The 10 per cent is only an estimate, and there is a big chance for error in arriving at that figure. No cost system is 100 per cent perfect, and if we can come fairly close, that is as close as we will come anyway, because there are chances for certain small errors in various parts of any system.

The Institute system's method of figuring loss is the one used by 95 per cent of the foundries. They simply add up their other items of cost and then add on a certain percentage of the total for loss. That is the simplest way of doing it.

CHAIRMAN A. E. HAGEBOECK: Regarding the percentage of normal referred to by Mr. Carter, that is a subject well worth while. Mr. Belt, just what is the percentage of normal? Certainly we should figure on a normal basis. What percentage would that be of the maximum?

ROBERT E. BELT: Each producer must figure out his own particular conditions. What is normal in one plant would not be normal in another. The relation of production to normal industry conditions would differ between different plants.

CHAIRMAN A. E. HAGEBOECK: Do you think that 70 per cent is about right for an average small foundry with no experience to go on?

ROBERT E. BELT: Offhand, I should say it would be somewhat dangerous to figure higher than 70 per cent, which would certainly be adequately high.

Every foundryman should bear constantly in mind that he should not apply his fixed overhead on the basis of actual operating conditions if production is in excess of normal. Quite a few foundrymen are doing that. One should always be guided by normal operations in the distribution of fixed overhead.

CHAIRMAN A. E. HAGEBOECK: What percentage would you say is normal, Mr. Runge?

E. T. RUNGE: Since the war, 67 per cent of the maximum.

J. B. GREENSTREET:* There seems to be some difference of opinion as to whether a 10 per cent loss on the total cost should be applied to the metal, since the metal is saved. Might there not be an easier method to overcome this objection, namely by adding 10 per cent on direct labor to all departments—that is, the 10 per cent overhead or some percentage of overhead?

In this way, the 10 per cent is then included in the cost, aside from the metal. In other words, if the melting department is left out and the 10 per cent is added to the other departments—to all the costs except the metal—would not that meet the objection? For instance, if it is figured that there will be a 10 per cent loss, 10 per cent of the core room charges is added to the molding department charges and to all charges in the melting room except the metal that is going to be recovered.

J. L. CARTER: It would not be right to add it in to overhead, so it

*Olney Foundry Co., Philadelphia.

would be applied to all work. The loss on one casting might be less than five per cent; on another it might be over 20 per cent. The loss must be placed on the individual job according to the estimate or record of what the loss is on that particular job.

If desired, the loss can be added on, leaving out the cost of metal. If that is done, one does not figure on the loss from the melting labor and other expenses.

J. B. GREENSTREET: That is the point I wish to bring out. Ten per cent is really an arbitrary figure anyway—it might just as well be five or 15 per cent. However, since it is 10 per cent, why could it not be left out of everything except the cost of the iron?

J. L. CARTER: All we can do in a standard cost system is to recommend the method that seems to be nearest the correct method and, at the same time, the simplest. We feel that this is the simplest way to handle it.

M. M. MARCUS: In taking the 10 per cent of the metal, it will make a difference. In selling, this sometimes means considerable money. It costs money to handle scrap, and it costs money to remelt. I believe the loss should be figured as 10 per cent of the total cost.

W. R. FISHER:* Mr. Carter, in the case of a molding floor, would you set up your molding machines on a machine-hour basis or on a direct labor basis?

J. L. CARTER: It would be our idea, in this system, that the simplest thing would be to make a separate department for the machine molding. If this is done, then direct labor and machine hour come rather close together.

MEMBER: Is the cost of metal figured at the spout or at the mold?

J. L. CARTER: The melting department ends with the delivery of the molten metal into the ladles at the spout of the cupola or furnace.

MEMBER: Mr. Carter, in figuring loss, do you think it would be better to take, for instance, the metal cost—which in most foundries would be perhaps five per cent—and put that loss on the cost of the metal? Then, coming to the direct molding cost, suppose the loss is six per cent or three per cent—whatever it is, that could be put on the cost of the metal.

In this way the losses in the various departments of the foundry could be kept track of, and, in time, those losses could be brought down by segregating the losses in the various departments instead of figuring the cost and, at the end, deducting the 10 per cent and assuming that that is the loss, or even figuring it from various departments in the foundry.

J. L. CARTER: The records of the loss in each department, or the loss chargeable against each department, are management records which one should have anyway in order to control operations properly. These records are kept even if they are not a part of the cost system.

On this whole question of loss, I want to say that the important

*Union Switch & Signal Co., Swissvale, Pa.

thing is for us all to agree to do it the same way. I do not think it makes much difference whether we do it the way suggested here or the way some others have suggested. That is a small matter. The point is, let us all agree to do it one way.

If we do that, results can always be checked by keeping track of actual loss and figuring the percentage in the same way that it is used on this estimate. Then, by comparing estimated results with actual results, the figure of 10 per cent is gradually corrected. Some may find that the loss ought to be 15 per cent; but if actual records are kept of the percentage of loss in the same way that it is estimated here, the estimated figure is bound to be checked, so that it will become more and more accurate.

It makes no difference whether it is done the system way or some other way, but it is important that we should all agree on one way to handle it.

MEMBER: Are the costs of securing business—the salesmen and advertising—included in the overhead, or not?

J. L. CARTER: That is included in general expense, and it is allocated to the departments on the basis of the total payroll of each.

MEMBER: If you figure your cost of metal at the spout, how do you take care of overhead? More iron always is being melted than is poured into the molds. Where do you put the cost of the metal not used?

J. L. CARTER: The iron that is not used goes back into the cupola, and because it does go back, less new pig iron is used. Therefore, the total cost of the melting department at the end of the month is less. The way this figure is arrived at is by taking the total actual cost of the melting department and dividing it by the total good castings produced, so that any little gain made that way is taken into account.

MEMBER: The metal that goes back is scrap, is it not? How do you arrive at the price set upon that scrap?

J. L. CARTER: One cannot go wrong if one takes account of everything that goes into the melting department—new pig iron, purchased scrap, labor, everything spent for the melting department over a certain period. If that is divided by the total good castings produced, I do not see how one can go wrong.

J. H. BERNARD:* I should think there would be a difference there in case, say, two jobs are being run, one with five per cent gates and sprues and another with around 60 per cent.

J. L. CARTER: We have that covered in the system.

(Mr. Carter then read from the Institute Cost System, the section on Distribution of Department Overhead in the Melting Department. See page 597.)

G. A. SWEET:† The direct labor dollar as a measure of overhead has been quite a subject of study to me. However, I lean toward the use of

*Erb-Joyce Foundry Co., Vassar, Mich.
†Milford Iron Foundry, Milford, Mass.

the direct labor hour, especially on jobbing work. With piecework or bonus—percentage of bonus—using the dollar as a measure, it seems to me that we want the man to produce as much and earn as much as he can.

Just because he earns more money, it does not seem to me that that can be applied on the basis of the dollar. He has just as much overhead, it costs so much to run the plant per hour rather than per dollar and I have found that it should be applied on the hour basis. Why was the dollar basis decided upon?

J. L. CARTER: In devising this system, we could not base it entirely on theoretical arguments of 100 per cent theoretical accuracy. I do not need to argue which method is the most accurate.

The reason why we decided on the direct labor basis was because it was the simplest, and the one which we thought we could get most foundries to use. If we had used the hour basis, a great many foundries would have been much more resistant to installation of the system, because that basis requires a little more work and it is somewhat more complicated.

Besides, we have taken care of this question very largely by advocating the subdivision into departments. If the squeezer machines are subdivided into a separate department, then the molding labor basis and the machine-hour basis are very similar.

J. H. BERNARD: This discussion might give the impression that 100 per cent is a good overhead. I believe that Mr. Runge can explain why a higher overhead is even better than a lower overhead.

E. T. RUNGE: We had a case where there was $10,000 worth of molding labor, $10,000 worth of expense for, let us say, 1c per lb., or 100 per cent of labor. In another foundry the molding direct labor was 20c per 100 lbs. The expense still was 1c per lb., which is 500 per cent. Thus, 500 per cent on 20c is $1.00, plus the 20c, is $1.20; also, 100 per cent on $1.00, plus another dollar, is $2.00.

Thus it will be noted that the 100 per cent costs $2.00, or more than in the 500 per cent example. If the overhead is below 150 per cent, I study it and, in most cases, find the production labor costs are high. When the overhead is higher than 150 per cent, the foundry in most cases is not efficient. There are exceptions, of course, but whenever overhead runs around 150 per cent, it should be studied carefully.

By reducing the productive labor cost per pound and raising the expense percentage to 300 or 400 per cent, nine times out of ten this will result in a lower total molding cost. If, in the example just given, the second foundry had been so efficient that they could produce for ½c per lb., then the overhead would be 200 per cent. Therefore, instead of being 2c, it would be 1.5c, the gain in reduced costs being ½c per lb.

CHAIRMAN A. E. HAGEBOECK: Another point in connection with this matter is that the cleaning is separate—it has a separate addition. Therefore, the molding percentage would be higher if the cleaning were in the molding department.

Simple Methods for Improvement and Control of Gray Iron Manufacture*

By Prof. L. F. C. Girardet,† Saint Die (Vosges), France.

Abstract

Recognizing that cast iron is a complex material which, because of this complexity, offers opportunities to provide castings of varying properties for special purposes, the author advocates practical control methods for securing the desired properties in the castings produced. Control operations are divided into three classes, for control of (1) mechanical properties, (2) metallographic structure and (3) chemical analyses. Tests used for control of these properties are described in detail, with particular emphasis given the Fremont shear test. This latter is advocated as showing the properties of the casting, an advantage over the use of separate cast test bars which show only the properties of the metal used. Rapid methods for metallographic examination of specimens to show structure and graphite characteristics are detailed.

1. The author's foundry is located at Saint Die, France, not far from the building where, toward the end of April, in 1507, a group of savants from the Vosges regions printed the famous work entitled "Cosmographiae Introductio" *(Introduction to Cosmography),* which constituted the act of baptizing America. It is in this book that the authors, taking into consideration the four voyages of Amerigo Vespucci, proposed to apply the name of "America" to the new world which they believed had been discovered by him.[1*] The author of the present paper, born at St. Die, addresses to the great America the greetings of the old godmother.

Iron

2. Iron is a complex material, most complex of the ordinary alloys. This very complexity makes it sensible to a great number of physical, chemical and mechanical factors. This is at once an advantage and an inconvenience.

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*Exchange paper of the Association Technique de Fonderie, the French Foundry Technical Association.

1*Reference numbers correspond with references in the Bibliography appearing at the end of this paper.

†Gear Foundryman.

3. It is an advantage because one can, taking advantage of proper conditions, develop at will this or that property, or diminish that or the other, so as to adapt the material to a particular use, such as with non-magnetic iron, iron capable of resisting corrosion, etc. It is also an inconvenience because, if one is not in control of the numerous factors which make for the condition of the iron, one may end by having a metal quite different from that desired, and with characteristics that are entirely unsuited for the purpose for which it is to be applied.

4. It is necessary, therefore, to conduct control operations which will permit the control of the variable properties to give the desired properties in the casting.

5. I have proven further[2] that this work can be done by simple and inexpensive means, and have described in detail the means I use.

6. As a result of general studies of the subject of cast iron, it is seen that its properties depend on its physical and chemical structure. Thus the problem which confronts the foundryman is to find, in the first place, the most suitable structure for the type of castings he is making, and then to seek the means whereby he may attain this structure.

7. I have given an example of a problem of this kind in the case of an iron of high mechanical strength.[3] Many of the general conclusions contained in this previously published paper are applicable in securing other properties.

8. In final analysis, the role which control plays is a double one. In the first place, it gives a check to determine whether the goal strived for was really reached. It also suggests, through the indications which it gives and from the conclusions one is able to draw therefrom, the changes or modifications which should be made to improve the quality of the castings.

CONTROL

9. It is understood that the control under discussion refers only to the metal itself—to the exclusion of factors due to the molding. The control such as I maintain embraces two types or classes of tests, namely:

(a) Test of the quality of the iron as it comes out of the cupola.

(b) Test of the quality of the castings.

10. Lengthy controversies arise among foundrymen of all

countries as to whether the quality of the iron as it comes out of the cupola is sufficient to define the quality of the castings. Nowadays it is an established fact that it does not. The test really only determines the characteristic of the sample itself, and not of the entire casting. However, this point of view resulting from undeniable facts has not yet entered common practice because, commercially, it is much simpler and more advantageous for the foundryman to guarantee the quality of iron than the quality of the castings, as the latter will have properties varying with the individual factors of molding and pouring. One can readily conceive that the foundryman adheres to this point of view, because it certainly is to his interest to do so.

11. Another point of view appears to have been developed particularly in France and Belgium. In both of these countries, tests of the quality of the iron used have not been neglected, but in addition their efforts have been toward controlling the quality of their castings, made easy by the Fremont method.

12. The great advantage the foundryman finds, is that of being able to improve his product, because he learns how he should prepare his iron in order to obtain the best results in each particular case. On the other hand, if he adopts this method of testing to the material received, it is the customer who is benefited, because he thus obtains reliable guarantees as to the strength of the castings.

13. However, risk for the foundryman is not as great as one might believe. After practicing this control for some time, his products are just right and the quality advertised is always attained, if he has allowed the slight margin necessary to offset the slight inevitable variations in practice. On the other hand, he has the advantage of having gained the good will of the customer, who is generally willing to pay a little more under such conditions.

14. Finally, adoption of control translates itself for the foundryman into an increase of his selling price and an extension of his business.

Control Practice

15. Control operations divide themselves into three classes, as follows:

1—The control of the mechanical properties.

2—The examination of the metallographic structure.

3—Chemical analysis and, eventually, corrosion tests also.

MECHANICAL PROPERTIES

Tests of Pig Iron

16. These tests should give information as to quality of the iron as it comes from the cupola and, consequently, as to its suitability for producing satisfactory castings. During the casting, some tests are made of the following:

(1)—Temperature of the iron as it leaves the cupola.

(2)—Pouring temperatures of castings of different kinds, and test pieces of shrinkage. (We make these measurements with the Chauvin & Arnoux pyrometer with disappearing filament.)

(3)—Test by impact with the railroad hammer on rough test bars of 40 x 40 x 200 mm. (1.57 x 1.57 x 7.87 in.) (This test is made in rare cases only.)

(4)—The Keep shrinkage test. Between the arms of a piece of iron shaped like the letter "C," two well-dried cores are placed having a groove of 20 x 20 mm. (0.787 x 0.787 in.) square section. This is covered by a dry-sand core having a pouring hole in the center of the arms of the "C" iron, which are planed and measure exactly 333.3 mm. (13.12 in.) between them. The iron is poured into this mold and the shaken out cast rods are measured cold with a large micrometer. The shrinkage found, multiplied by three, gives the shrinkage per meter.

(5)—The hardness test is made on the same test piece which is broken off at a bevel on the ends, the depth of the hardness being measured by means of dividers.

17. These few tests suffice for determining initial iron. To these tests may be added a bending test, made on the shrinkage test piece, whose section is rather constant.

Tests Made on Finished Pieces

Test of Surface Hardness

18. This test is made at several points on the piece by use of a portable ball testing apparatus (Turpain test kit). It gives information in regard to the hardness of the skin but not of the deeper regions, which we will examine later on by means of the micrometric ball test (test of internal hardness).

Shearing Test

19. This is the most important of mechanical tests. It has given rise to a large number of controversies. For my part,

after having used it daily for a good many years, I have come to the following conclusions:

(1)—The shearing test is the best mechanical test of cast iron, from the practical point of view.

(2)—It is essential that the test pieces or cylinders used should always have strictly the same section. Otherwise, the determinations are subject to very appreciable and varying errors, which cannot be eliminated by any manner of correction.

(3)—The arrangement of the shear apparatus must be such that no side play can occur.

20. The condition (2) is never observed; item (3), which depends on the construction of the machine and on its present state after use, is not always controlled with sufficient care. The divergence of results and the anomalies found by capable and conscientious investigators certainly do not result from any factor other than wear of the shear apparatus. I believe that it would not be amiss for me to give some explanations of this essentially important point.

21. At various points suitably selected, we cast tapered test pieces on a casting having a base with a diameter of 30 mm. (1.18 in.), a height of 30 mm. (1.18 in.) and a diameter of 25 mm. (0.98 in.) at the smaller end. These small masses, adhering to the casting, will practically have the same thermal history as the casting itself, at the spot where these are located.[10, 11]

22. These test pieces are detached with a chisel at time of trimming the casting, for the purpose of serving later as test pieces for the Fremont test.

23. For this purpose, the test piece is placed in a hole in a piece of hard wood, which is fastened to a disk attached to a lathe center. A guide hole is bored of 13 mm. (0.51 in.) diameter and 3 to 4 mm. (0.118 to 0.157 in.) deep, then the drill is replaced by the Fremont trepanning drill (of Bonvillain & Ronceray). The chips are collected in a tin box and will serve for the analysis.

24. This method of operation presents some advantages: The drill is well guided, the elimination of the drillings is readily accomplished and erosion is diminished. One may have a whole series of blocks and drill all of the guide holes without changing the drill, then make all the test pieces in another separate operation.

Shearing

25. The test piece pulled out by means of an extractor is sheared in the Fremont machine (Bonvillain & Ronceray). These pieces are collected to serve for the metallographic examination and for the internal ball hardness test. The average diameter of the sheared section is measured with a micrometer reading in hundredths of millimeters, and it is to this section that the shearing load is compared.

26. Unfortunately, test pieces are not always cylindrical—their section is not round; they are always slightly tapered. They are obtained of more regular shape by drilling them by hand, but this takes too long.

27. Moreover, resistance to shearing decreases much faster than the section, when the latter decreases and the measurement is falsified to an extent beyond correction. Undoubtedly other investigators have observed this, as considerable attention has been paid to improvement of the drill. Mr. Guillery[12] and the Association of Belgian Foundrymen[13] have described improved drills.

28. Another source of considerable error is the play of test piece in the shear-test apparatus. This play, which depends on the thickness of the specimen and the wear of the machine, causes premature breakage through bending and offsets the measurements completely. This play should be eliminated entirely.

29. Many devices have been proposed, by Belgian foundrymen[13] and by E. V. Ronceray.[14] I myself have tried to hold the test piece in a handle of hardened steel, and it worked out satisfactorily. However, the final solution which I have just recently adopted appears more preferable, as it solves the problem of the constancy of the sheared section and, at the same time, the absence of play in the clamp or jaws.

30. It consists simply of a slightly tapered specimen, obtained by means of a suitable drill. This specimen is set into a hole of the same taper, drilled into a small hardened-steel cylinder in which the diameter of the hole, at the straight part, is just 5.64 mm. (0.222 in.). The specimen is forced into this hole and is held by means of a screw which presses against it (Fig. 1). The whole is placed in the clamp (suitably modified) of the shearing machine, the shearing being done just at the point where it extends over, always acting against a section of 5.64 mm. (0.222 in.).

THE METALLOGRAPHIC EXAMINATION

31. The metallographic examination is of greatest importance, a point which I have urged on various occasions.[11] It should become still more common than the ball hardness test. With the metallographic examination and the shear test, one has an efficient control of production, making it possible to find, in a certain measure, the cause of the defects noted.

32. One finds at the present time, in all countries, simple microscopes which are not expensive nor excessively large, intended for this purpose. They permit photographing by means of a portable photo attachment. Generally, small, round pictures of 40 mm. (1.57 in.) diameter are taken, which may be enlarged with ordinary commercial apparatus.

33. Photomicrographs reproduced in this paper were obtained in the above manner, then enlarged to double the original diameter. I have described in detail in a previous publication[11] all of this apparatus and its working method.

Polishing

34. The samples may be readily polished by dressing them

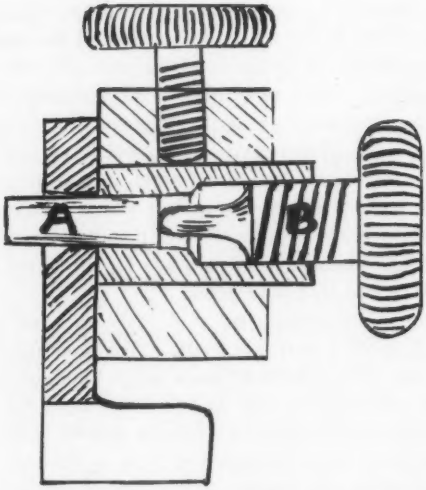

FIG. 1—DEVICE TO ELIMINATE PLAY OF TEST PIECE OF SHEAR-TEST APPARATUS. SPECIMEN TO BE TESTED *(A)* IS TAPERED SLIGHTLY, FORCED INTO HOLE OF SAME TAPER DRILLED IN SMALL HARDENED-STEEL CYLINDER AND HELD IN PLACE BY SCREW *(B)*.

up with a file, then passing them successively over sheets of emery paper of increasing fineness, and finishing on a strip of cloth moistened with a paste of colcothar, stretched over a board. It is by this simple although very long method, that one obtains the most perfect polished specimens.

35. For control of manufacture, speed is necessary. After various trials, I decided upon the following arrangement, which is very rapid and sufficiently efficient:

36. Two ordinary polishing stands (Fig. 2) are driven by one electric motor. The first stand carries on one side an emery wheel, one face of which may be sprayed with a stream of water. On the other side of the stand there is a zinc disk covered with emery cloth, then a wooden disk and another zinc disk covered with a finer cloth, the whole being tightened with a screw.

37. The second polishing stand is fitted with zinc disks covered with fine emery paper on the one side, and still finer emery on the other. The other shaft carries a wooden disk to which a piece of cloth is glued. This is enclosed in a housing,

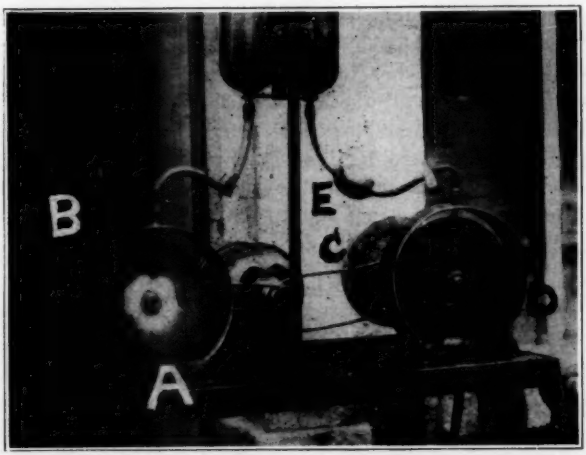

FIG. 2—APPARATUS FOR POLISHING TEST PIECES ON PRODUCTION BASIS. STAND ON LEFT HAS EMERY WHEEL *(A)* ON ONE END OF SHAFT; ON OTHER END, A ZINC DISK COVERED WITH EMERY CLOTH, A WOODEN DISK AND A ZINC DISK, ALTERNATELY *(B)*. STAND ON RIGHT HAS ZINC DISKS *(C)* COVERED WITH FINE EMERY PAPER ON ONE END OF SHAFT; ON OTHER END, WOODEN DISK *(D)* COVERED WITH CLOTH AND MOISTENED WITH WATER AND COLCOTHAR BY MEANS OF BULB *(E)*.

and the disk may be sprayed with water containing colcothar in suspension. The rubber hose which supplies the liquid carries a bulb, it only being necessary to press it in order to stir the powder into suspension.

Mounting the Specimens

38. We have to polish two distinct kinds of specimens, namely, specimens of irregular shape—which have been taken as samples at time of inspections—and specimens for production control. I shall not go into the first ones, for which complete, useful information will be found in the treatises on metallography. The control specimens have the great advantage of presenting regular shapes, which facilitates rapid work when handling large numbers of pieces.

39. A small hard wood block has 3 triangular notches, as shown in Fig. 3. Two strips of thick brass, placed on both sides of the block, may be tightened on to it by means of two screws. Into the three notches one places simultaneously three of the test pieces and the assembly is turned over on a sheet of zinc, placed on a mirror having an opening. The projecting specimens are adjusted so that each will extend from the block the thickness of the sheet of zinc. The screws are tightened up and other blocks are prepared in the same way, depending on the number of specimens to be examined.

40. As soon as all the blocks are ready, polishing stands are started and the first block is applied against the dry face of the grinder, being held against it until the specimens in the block are on the same level. Then the block is passed into the right hand and applied against the moistened wheel face.

41. With the left hand, one grasps the next block so as to

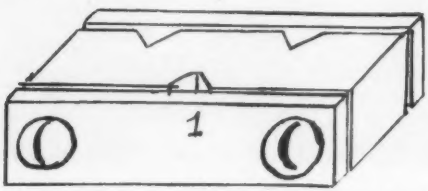

FIG. 3—APPARATUS FOR MOUNTING TEST PIECES FOR EXAMINATION ON PRODUCTION BASIS. HARD WOOD BLOCK HAS THREE TRIANGULAR NOTCHES AND TWO THICK STRIPS OF BRASS ON BOTH SIDES OF BLOCK, TIGHTENED BY SCREWS. THREE TEST PIECES ARE INSERTED IN NOTCHES AT ONCE, AND ASSEMBLY IS TURNED OVER ON SHEET OF ZINC, PLACED ON A MIRROR HAVING AN OPENING. TEST PIECES EXTEND FROM THE BLOCK THE THICKNESS OF THE ZINC SHEET.

smoooth it down on the dry surface of the wheel. It replaces the first as soon as polishing the latter has been completed on the wet face, when one passes it to the emery cloth disks, and then it is applied on the second stand, ending with the cloth disk.

42. In working with one hand, the time necessary to finish three specimens from the rough fracture up to the mirror polish is about three minutes; by working with both hands, one minute is gained. Thus, the duration of polishing one specimen may be less than one minute.

43. The disks covered with emery last a long time. It is only necessary to turn them when one face is worn. One may also have several disks prepared in advance.

Microscopic Examination

44. A block of hard wood, 20x20 mm. (0.787 x 0.787 in.) square section and 70 mm. (2.75 in.) long, has 12 holes drilled in it of 6.7 mm. (0.239 in.) diameter. The block has been soaked in melted vaseline to make it waterproof. In each hole a ball of modeling clay is placed, and into these the specimens are inserted with the polished face up.

45. The block is turned over onto a mirror and, with a small bar of iron, the clay is pressed into the bottom of each hole. All 12 of the specimens are thus fixed flush with the face of the block in contact with the mirror. The block then is turned over and placed under the microscope for examination for graphite.

Graphite

46. Graphite is of foremost importance from the standpoint of the useful qualities of the iron. Therefore, I shall go into the matter somewhat extensively, explaining briefly the new method which I use for investigating graphite.

47. The examination of graphite is done habitually on the polished specimen without acid attack. However, by this method one sees only the out-croppings of the lamellae included in the metal, the particles of small dimensions being entirely invisible. The eutectic graphite, which is the most interesting, happens to be present in very fine particles and, therefore, usually cannot be seen at all.

48. If a polished iron specimen is moistened with acid, quite regular attack of the entire surface is noted, regardless of

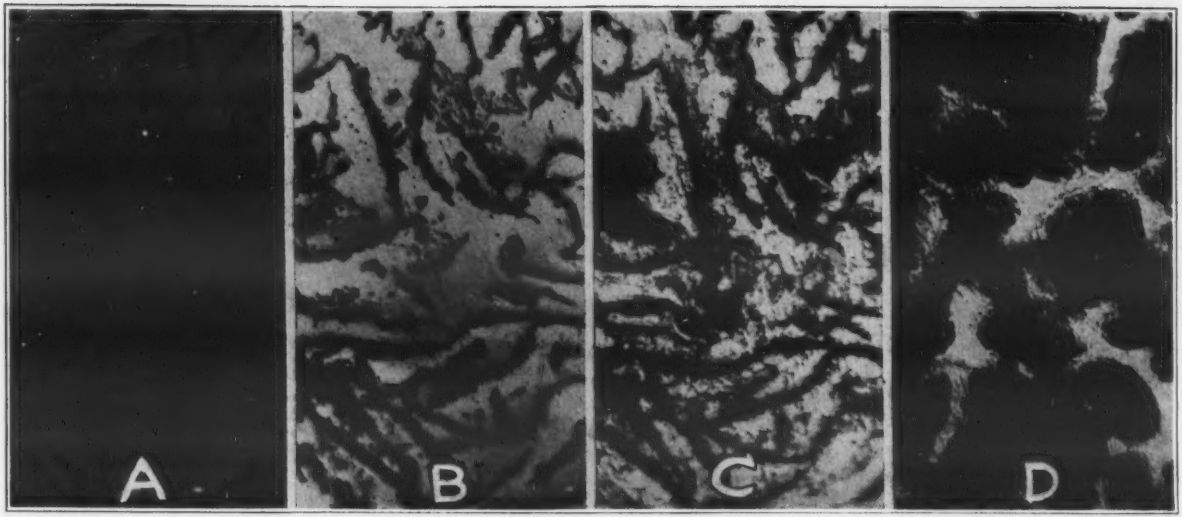

FIG. 4—ACTION OF REAGENTS ON CAST IRON. *A*, *B* AND *C* ARE IDENTICAL SECTIONS.

A: WITHOUT ETCHING. *B:* ETCHED SLIGHTLY WITH CHROMIC REAGENT. *C:* MORE STRONGLY ETCHED WITH CHROMIC REAGENT. *D:* SAME IRON AS *A*, *B* AND *C*, BUT ETCHED WITH PICRIC ACID FOR PEARLITE DETERMINATION.

the form of the graphite. But graphite is insoluble in acids and each particle of graphite becomes the cathodes of a short-circuited cell and, theoretically, metal should dissolve more rapidly around it. Actually, this is not so at all, because polarization rapidly intervenes and stops the accelerating action of the graphite.

49. If we now add a depolarizer to the acid, this local action will reappear and each grain of graphite will dig around itself. After several tentative trials, I hit upon the following reagent, consisting of an acid, a depolarizer and an accelerator:

Hydrochloric acid, cc	25
Water, cc	100
Chromic acid, grams	10
Anhydrous chloride of nickel, grams	5

50. The reagent is placed on the specimen with a glass rod. It is left on for a few seconds, then absorbed with a blotter and washed off with ammoniacal water. It is dried by passing over a brush dipped in a little denatured alcohol, containing 10 per cent ether, then blown with a bulb.

51. The mechanics of the reagent's action are plainly visible in Figs. 4A, 4B and 4C, taken on the same spot on a piece of pig iron. Fig. 4A is without etching; Fig. 4B, etched slightly by the chromic reagent, and Fig. 4C, more strongly etched. Fig. 4D is the same iron, attacked by picric acid for determining pearlite.

52. Fig. 6A was taken on a piece of a piston ring. We note the appearance of spots, which were not apparent previously. These black spots are the orifices of small depressions, hollowed out by each minute grain of graphite corroding around itself. These grains undoubtedly are real eutectic graphite, deposited at the instant of the separation of the eutectic. [11, 15]

53. Figs. 4A, 4B, 4C, 4D and 6A were selected so as to show the quite different structures of the pig irons. However, it is in the study of iron of close grain after remelting that the use of the reagent is particularly useful, because in these remelted irons the graphite is so divided up that its outcropping is almost invisible.

54. Attack by the reagent shows the form and amount of the ramified flakes of the graphite, as well as their distribution. It also causes the eutectic graphite to appear, which is a sign of quality. One thus succeeds in distinguishing irons which ap-

pear to be similar, and I have been able in this manner to reveal the origin of porous spots in automobile cylinders.

CLASSIFICATION OF THE STRUCTURAL ELEMENTS BY MEANS OF COMPARISON SCALES

55. The result of a metallographic examination is difficult to express, hence one most generally disregards it and makes a photograph. To preserve a photograph or the small specimen itself, however, accumulates records which are difficult to consult. Therefore, I have endeavored to designate by numbers each of the different aspects obtained, and this is quite sufficient for usual purposes.

56. In a block of wood identical with that serving for the examinations, I have ranged 12 specimens, classified from 1 to 12 according to the increasing fineness of the graphite. I call this the "graphite scale."

57. When examining for the graphite, I slide this block past the one containing the specimens which have been studied, and for each of them I determine the number on the scale which most resembles it in appearance. If it is No. 3, I write "3" in the graphite column of my record of analyses. If it is more than "3" and still not up to "4," I put down "3.5."

58. In the same manner I have prepared a scale for pearlite, for steadite and one for ferrite. The results of the examination thus are classified by means of four figures placed, respectively, in the columns *G*, *P*, *S* and *F* of the record. These figures always make it possible, through reference to the scale, to find again or recognize the appearance of the specimen thus classified.

Pearlite

59. Examination for pearlite is done quickly by coating the specimen (using a brush) with a 4 per cent alcoholic-picric acid solution. The specimen is dried with a blotter and then brushed with an alcohol-ether mixture. The attack on the 12 specimens lasts for 30 seconds, after which each specimen is dried with the air bulb and examined as for graphite, with the corresponding comparative scale.

Micrometric Ball Test

60. The micrometric ball test, which should be in the mechanical tests, is logically in its place here, as it is made on the specimens examined for pearlite; one thus obtains clearer outlines.

61. We have seen that the ball hardness test, as usually made, gives the hardness of the skin, and not that of the inside of the piece. In order to obtain this interior hardness, I have constructed a small lever machine, as shown in Fig 5, provided with a ball of 1.58 mm. (0.06 in.) diameter. The proportions of the machine have been so calculated that the hardness figure obtained corresponds to that which would be obtained with a ball of 10 mm. (0.39 in.) and a load of 3,000 kilograms (6,613.8 lbs.). Each machine, nevertheless, is subjected to an experimental check with specimens of known hardness, which assures accuracy.

62. The measurement of the diameters of impressions is made by means of a micrometer eye-piece, at the same time that the pearlite examination is made. Two rectangular diameters are measured and the average is taken.[11] The approximation obtained is around 1 to 1.5 per cent.

63. For the ball hardness test, specimens are taken out of the block and fastened in the cups of a block of lead, seen in Fig. 5. They are replaced in the wood block after the ball test.

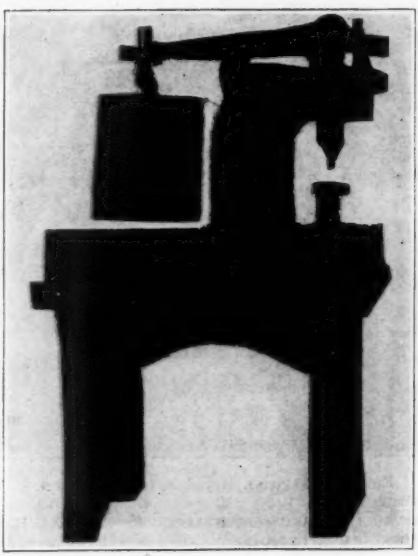

FIG. 5—LEVER MACHINE FOR DETERMINING INTERIOR HARDNESS OF CAST IRON.

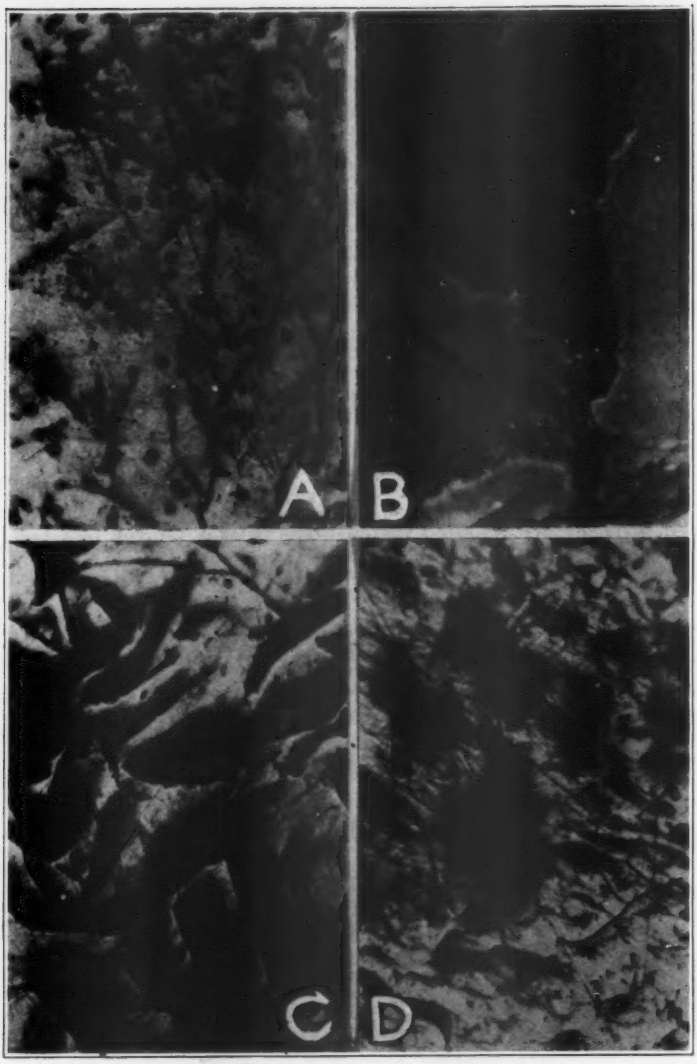

FIG. 6—GRAPHITE EFFECTS IN CAST IRON.

A: SECTION OF PISTON RING, SHOWING BLACK SPOTS OR DEPRESSIONS CAUSED BY CORROSION OF GRAPHITE GRAINS. *B:* SHOWING HOW ATTACK OF REAGENT IS STOPPED WHEN SURFACE OF SPECIMEN IS RUBBED WHILE REAGENT IS BEING APPLIED. *C:* GRAPHITE OF IRON, AT TIME SPECIMEN IS PLACED IN GYRATORY STIRRING APPARATUS. *D:* GRAPHITE OF IRON, SHOWING GRAPHITE AT TIME SPECIMEN IS LEAVING GYRATORY STIRRING APPARATUS.

Steadite

64. In the common irons, phosphorus always exists in the eutectic state—so-called "steadite," which must be distinguished from cementite. Usually cementite reagents also color steadite.

65. Portevin has described a handy reagent, because it reacts in a cold state and colors only the phosphorus of the iron. This reagent is the hypobromite of soda. Unfortunately, it must be prepared at the moment of using it, as it does not keep, and handling bromide is difficult. To avoid this disadvantage, I have modified the reagent by making two solutions as follows:

SOLUTION A

Potassium bromide .....15 grams
Water .....30 grams

Dissolve and add:

Bromine .....15 grams

Shake and keep in a drop counting bottle, *with ground stopper.*

SOLUTION B

A 40 per cent caustic soda solution in water. Keep in a drop counting bottle *with rubber stopper.*

66. At the time of use, I mix 5 to 10 drops of solution A in a watch crystal with the same amount of solution B, stirring with a glass rod. With the latter, I place the reagent on the specimens placed in the blocks. After about two minutes, I sponge them off lightly, brush slightly with ammoniacal water, sponge, wash with alcohol and dry. Care must be exercised not to rub the surface of the specimens, which would stop the attack (see Fig. 6B). The iron phosphide becomes yellow in color, occasionally blue.

Cementite

67. Cementite is subject to being attacked by boiling picrate of soda. A very advantageous arrangement is an electrically heated apparatus, such as I have previously described[2] and which I have used without any change for five years.

Ferrite

68. Ferrite alone remains bright after the double attack for pearlite and cementite-steadite. It is often seen without going to the double attack.

THE CHEMICAL TESTS

69. For a long time chemical analysis has been given an importance which it undoubtedly has, but with the application

of the present methods no advantage is derived from this information of the analysis. The analysis of the iron as it is performed only furnishes us with information in regard to the percentages of the most abundant of the simple elements: C, Si, P, Mn, S. It does not tell us anything in regard to the manner in which they are related in the iron, and only metallography furnishes us with some data on this point.

70. However rudimentary may be the results, chemical analysis is indispensable, and I have described[2] the methods and apparatus which enable us to make the usual determinations quickly and economically. I have not found it necessary to make any change in the methods since publishing them.

Corrosion Tests

71. Corrosion tests evidently are a part of chemical tests. As they are made at the present time they have, above all, the aim to furnish information to the user and not to the foundryman. At my instigation, J. P. Girardet[16] has studied a method permitting the foundryman to determine the best composition of the iron to resist a specified reagent, to make comparisons between irons, etc. The duration of the operations is short, as one operates on the filings in motion in the reagent.

CONCLUSIONS

72. The foundry is steadily proceeding toward scientific methods with which it was unprovided up to recent years. It is to be expected, therefore, that the trade will become more and more exacting. One might ask whether, if it has been demonstrated that good iron poured under certain conditions gives poor castings, whereas a poor iron will give good ones, how long will the trade be content with the test of the quality of the iron by means of test bars?

73. In any event, the foundryman should prepare now for a tremendous change. Does this mean that the small foundries will disappear for lack of being able to adapt themselves to the new conditions? Perhaps, but in every case I have been able to prove by my own personal experience of five years that one can carry on—with little expense and without devoting too much time to it—a scientific control of manufacture which brings about appreciable improvement.

74. To sum up the results I have obtained and difficulties encountered in actual experience, the first difficulties arose by

reason of the physical and chemical variability of the iron as a raw material. They were solved by a chemical analysis and an examination of the physical structure.

75. The cupola, however, does not furnish fully homogeneous iron, as I have remarked elsewhere,[3] and it also is necessary to be able to vary the nature of the iron during the course of one cast. The control tests which I have made have shown me how deceptive are the usual methods employed, and also how some charges change during their passage through the cupola.

76. Finally, there is heredity, causing some irons to have a bad influence, or a good influence, which their chemical composition does not in any way explain. I have discussed this question at length[3] and will go into it again. It appears, however, that it is caused mainly by the graphite of non-eutectic origin, which is an inclusion.[11]

77. These considerations lead me to admit the need for stirring the iron in order to mix it well. Study in the laboratory with glass apparatus, with all known methods of agitation—whirling, jolting, etc.—have led me to prefer the so-called "gyratory" stirring.

78. Properties of the gyratory method are singularly well adapted to the problem, because (1) it does not necessitate any moving instrument in the iron; (2) it takes place without jolting, with a slight cost for motive power, and does not damage the cupola lining; (3) it emulsifies finely all substances of similar specific weight, and rapidly eliminates the others, which collect together in the center of the free surface if they are lighter, or in the center of the bottom if they are heavier.

79. Properties in (3), above, are particularly important, because the slag included in the iron—the sulphide and particularly the free graphite—are rapidly brought to the surface. A demonstration of this is shown in Figs 6C and 6D, in which the graphite of the iron is seen on its entry and upon its emerging or leaving the apparatus. Graphite spangles of the dross have disappeared; structural elements are finely emulsified.[15]

80. Having this apparatus, which reduces greatly the number of variable factors acting on the liquid iron, it is much easier to systematically study the effect of the various additions which become a part of the iron. One can thus determine, in each case, the iron best adapted to a specified product— to give the casting the highest quality of mechanical properties.

81. A problem which frequently confronts foundrymen is that of duplicating for an old customer a casting already delivered some time before, and which has to be replaced. The casting having furnished good service, the customer figures that the same iron composition will apply to the new part.

82. However, I recall a case wherein a compressor base lasted for twenty years in a chemical products plant. The one furnished to replace it by the same foundry lasted six weeks, and the foundryman who built it according to the same methods, with the same formula of iron mixture, could not understand it at all, as the chemical analysis was practically the same for the new as for the old casting.

83. Metallographic examination immediately furnished an explanation: The new iron contained graphite in very long filaments, and a badly formed pearlite. It was a ferritic iron, containing an abundance of foam-like graphite, which is in the best of condition for rapid corrosion. This is one example among a thousand similar ones.

84. If the foundryman of yesterday could operate according to recipe as a cook does, it is not the same today. The blast furnace technique has changed and the products of specified origin are no longer comparable with those of yesterday. They even vary greatly from one lot to another, if one is not careful.

85. One last example, in conclusion: Small porous spots developed along the bore of one of the cylinders of a 4-cylinder engine block. What they could be attributed to was not known. Metallography revealed nothing, the iron was good and relatively homogeneous in the different parts of the block.

86. The method of examining graphite by means of corrosion gave the key to the puzzle. The graphite of the porous region was quite similar in appearance to that of the neighboring sound portion; but after treating it with the chromic reagent, the appearance changed entirely.

87. In the porous regions, graphite was in flakes formed of fine networks, in spongy formation. Furthermore, the filaments were distributed without clusters. As soon as a micrometic ball test was made on top of one of the flaky clusters, the penetration was deep, the metal crumbling in the cavity.

88. Why flaky clusters at this spot? Because it was a dead spot where the iron had stopped; the foamy graphite, therefore, immediately started to increase, and as soon as the strains re-

sulting from the solidification began to develop, the iron gave way at these spots, causing minute cracks.

89. Under such conditions two remedies are available: By changing or cleaning the iron to eliminate the foamy graphite, or by rearranging the pattern and changing the location of the risers. The best remedy would be to make both changes at the same time.

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Care and Maintenance of Fuel-Fired Furnace Linings in the Nonferrous Foundry*

By H. E. White,** Pittsburgh

Abstract

The discussion of refractories is divided into two sections, one on the open-flame furnaces and one on the nonferrous melting cupola. The open-flame furnaces are listed as (1) vertical barrel type, non-rotating; (2) horizontal barrel type, rotating, and (3) egg-shaped tilting type. Data secured in 1926 and 1929 surveys are compared; these show a decrease in use of fireclay refractories and an increase in silicon-carbide and the alumina-silica, mullite and aluminum-oxide types. Causes for failure are analyzed. While these causes are numerous, spalling and improper furnace atmospheres are two of the most important. Types of available lining materials are listed and discussed. Proper installation is stressed, drying and glazing being of special importance. Factors conducive to long life are listed as follows: Proper installation, thorough preheating, proper glazing before using, daily inspection, hot patching when needed, weekly cold patching and the use of mild cleaner to remove accumulated slag.

Open-Flame Furnaces

1. Every foundryman is acquainted with nearly all of the types of open-flame furnaces common to the nonferrous casting shop. Either gas or oil or both can be used in these furnaces, and they are of the following general types:

(1) Vertical barrel type, non-rotating.

(2) Horizontal barrel type, flame directed from one end only, rocking through a portion of a circle.

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*Prepared by the author under the sponsorship of the Nonferrous Survey Sub-Committee of the Joint Committee on Foundry Refractories.

**Lava Crucible Co. of Pittsburgh.

(3) Horizontal barrel type, rolling in one direction through a complete arc, flame from both ends.
(4) Egg-shaped tilting.

2. The exact reason for the adoption of each of these furnace types is not clear in all cases. High metal losses are overlooked in favor of cheap melting of large units. In general, the following are the influencing factors:

Heavy work where emphasis is given on production and low cost rather than quality.

A large proportion of scrap melted.

Heavy fluxes necessary, due to the nature of the metal melted or some other involving factor.

Cheap metals allowing relatively high metal loss.

Table 1

TYPES OF LININGS USED BY REPRESENTATIVE GROUP OF FOUNDRIES IN 1926 AND 1929.

	1926	1929
Number of foundries investigated	41	36
	Percentage of Users	
Fireclay type	68	44
Silicon-carbide type	15	34
Alumina-silica mullite or aluminum-oxide types	3	11
Unknown	14	11

3. From the original questionnaire[1] sent out by the Joint Committee on Foundry Refractories in 1926, it was found that the largest proportion of the furnaces investigated were lined with ordinary firebrick. This represented 62 per cent, and the average heat life of these linings was 785. Six per cent of the furnaces were lined with plastic brick at an average heat life of 300 heats, and 15 per cent with silicon carbide materials at an average heat life of 980 heats.

4. It is not exactly fair to compare lining life on the basis of the initial lining used. The properties and use of the maintenance cement affect this to a great degree, as do the furnace practice and metals melted.

5. There are widely variant instances using, as near as can be ascertained, the same lining materials and having the other factors comparable. Two of these cases are on record, both using

[1] *Preliminary Report of Sub-Committee on Survey of the Nonferrous Foundry Industry.* TRANS., A. F. A., vol. 36, pp. 136-145 (1926).

similar types of furnaces and similar firebrick linings. One averaged 75 heats per lining using fireclay and sand for repairing the lining, and the other obtained 1500 to 2000 heats using a so-called super-refractory maintenance cement.

6. Then, too, there are evident discrepancies in reporting the data from the various foundries. Table 1, a comparison between 1926 and 1929, covers types of linings as used in the most representative group of foundries using this type of melting equipment.

7. Note, in Table 1, the remarkable increase in both the silicon-carbide type and the alumina-silica type. The decrease in the unknown types which represent the disinterested consumer is pleasing also.

Some Causes of Failures

8. Refractory linings in these furnaces fail from a number of causes, some of which are peculiar to this type of furnace. These are as follows:

(a) Spalling (low resistance to thermal shock).
(b) Cutting action of the flame.
(c) Fluxing action of floating slags.
(d) Fluxing action of particles of slag thrown against the refractory by the blast.
(e) Mechanical injury due to charging heavy pieces of metal.
(f) Chipping out adhering slag.
(g) Low P. C. E. for temperatures involved.
(h) Disintegration by metal penetration.
(i) Penetration by liquid or gaseous fuels.
(j) Chemical attack by various metals and fluxes.

9. In addition, the following factors should be considered by the purchaser:

(1) Heat conductivity.
(2) Ease and convenience of installation.
(3) Physical behavior on pouring.
(4) Ease of maintenance.
(5) Mechanical strength.
(6) Least possible change in volume under all working conditions.
(7) Durability, or the ability to retain its good qualities after long period of use and abuse.
(8) Uniformity—chemically, physically and mechanically.

Spalling

10. The action of spalling has frequently been misinterpreted. An ordinary open-texture firebrick, quite resistant to spalling from heat shock alone, frequently will spall readily when used metallurgically under certain conditions. This has been traced to slag or metal vapors condensing in the refractory pores and disrupting the refractory structure on cooling.

11. Attention is drawn particularly to this as the cure for spalling; i. e., the use of a more-open-texture structure would be the extreme opposite here. What really is needed is a dense structure to keep out the slag vapors, or else the proper glaze, or both.

12. The effect of furnace atmosphere on refractory linings should be considered. Highly oxidizing conditions form oxides of the nonferrous metals quite readily. These oxides—and especially that of lead—become very active fluxes which readily attack clay, silicon-carbide and other super-refractory lining materials.

13. Strongly reducing conditions may cause disruption of clay refractory shapes by carbon deposition. On the other hand, this condition has little or no effect on silicon-carbide linings.

14. Chromite linings may be disrupted under these conditions by reduction of the iron content inherent in the material.

Types of Linings Available

15. Naturally, the original lining material used should be considered first. Firebrick of good quality still serves admirably for a large number of cases. Care exercised in installation will easily be repaid by increased life.

16. The use of super-refractory cements, which add only a small amount to the total lining cost, will more than repay the initial outlay. By the use of these cements, metal penetration in joints is reduced. This is especially true of joints parallel to the direction of the flame.

17. A strong cutting and erosive action combined with high temperatures takes place wherever the flame impinges on the furnace wall, and where a joint is present the action is accelerated. Most super-refractory cements contain, as a major portion of their inert ingredient, refractory grog of an abrasive nature admirably adapted to withstand this cutting action.

18. To overcome somewhat the above trouble, and to make the initial installation easier, there is a tendency for lining

manufacturers to make their linings in large pieces with consequent fewer joints. Some, in fact, have joints only perpendicular to the direction of flame travel.

19. Due to the fact that the lining manufacturer did not observe the above conditions, the first plastic linings were able to achieve success, and for a time they kept well ahead of the pre-fired types. They naturally present no joints left open for attack, but are quite difficult to install properly.

20. Various mixtures have been tried in plastic linings and, in spite of some of its disadvantages, silicon-carbide seems to be the most popular for this type of lining.

21. Experiences with plastic mixtures containing silicon-carbide show inconsistencies in results obtained by different users. In many respects it is an ideal brass-furnace refractory, since it is almost entirely free from cracking and readily forms a vitrified surface which is very resistant to heat or ordinary wear.

22. With high-zinc alloys containing little or no lead, its resistance to metal penetration recommends it highly and its use meets with almost unvarying success. With percentages of lead in excess of three per cent, various users report most radically different results. Some have no difficulty at all; others get good results part of the time.

23. Mullite, including converted sillimanite, andalusite and cyanite, offers distinct promise; but in plastic mixtures it is difficult to bond without impairing its good qualities. Properly bonded and properly handled, it is quite free from spalling, cracking and metal penetration.

24. Chrome-ore refractories have not as yet seemed as promising as mullite or silicon-carbide mixtures for this type of lining.

25. Super-refractory pre-fired linings are becoming more plentiful. The mullite bearing and high-alumina mixtures in large shapes for minimum of joints, are the most popular. Here the refractory can be properly bonded and is free from the unstable conditions of firing where plastic mixtures are used.

26. In fact, they overcome all of the objectional points mentioned earlier in this paper. They are of low thermal conductivity, are easy to install and maintain, are uniform chemically and physically, do not change in volume under working conditions and they pour clean and do not readily slag.

27. Proper firing at extreme temperatures is necessary to

impart the most desirable qualities in mullite shapes. Unfortunately, some of the manufacturers do not as yet conform to this.

PROPER INSTALLATION

28. Most open-flame furnaces at some time in their career have encountered conditions which warp the shell or steel jacket out of shape. This may be due to an actual burn-out through metal seepage, or due to letting the old lining get too thin.

29. Every one familiar with this condition knows what a job it is to bring the shell back to its original shape. However, in the interest of lining life, the original contour of the furnace shell should be approached as nearly as possible before proceeding with the lining, otherwise considerable chipping of refractory shapes with accompanying ragged joints may result.

30. The usual procedure in the manufacture of pre-fired block-type linings is to allow some space, usually 1 to 1½ in. for shell variation. In the case of non-silicon-carbide type linings, this can be filled with a mixture of foundry sand and clay or, better, crushed brick and clay in the proportions of 75-25. Other plastic mixtures of low-drying shrinkage may also be used.

31. To give the lining proper support, it is best to assemble the important sections on the foundry floor and then cut out a template or sweep, closely approximating the outer contour of the lining. With the aid of this sweep the plastic material may be molded against the shell and a substantial foundation for the lining thereby obtained. The success of the lining depends greatly upon this foundation, and often too little attention is paid to it.

32. With highly conductive materials such as silicon-carbide, the foundation material should be an appreciable thickness of heat insulation (at least 1½ in.). Diatomaceous earth, asbestos or similar material may be used with sufficient binding agent to hold it together.

33. The lining may then be installed, allowing for minimum joints properly filled with cement, and the pieces carefully set in place. If instructions are given by the manufacturer, it is always best to follow these to the letter.

34. After the various pieces or blocks have been set in place, a small amount of time spent on carefully filling and pointing up any joints or cracks and then giving the entire installation a cement wash, is money well spent.

35. Linings made from plastic refractories require considerable experience for successful application. With silicon-carbide plastics, the heat-insulating material must be used similarly to the method just described. This may be furnished in a quick-setting mixture for this purpose. The ingredients added do not materially affect the insulating properties of the material. With plastic refractories of low heat conductivity they often can be applied directly against the furnace shell with this apparent advantage.

36. A word of caution in the use of plastics. It not only is necessary to have the material moistened to the proper consisitency, but it should stand at least 36 hours in this condition to get the best results. This allows the bond to go entirely into solution.

37. With material which has dried out due to standing, its original condition should be restored. The lumps should be broken up carefully, the entire batch carefully moistened and carefully mixed, taking particular care to mix with a kneading action so that the water works into the pores of the refractory. This is accomplished in special machines in the manufacturer's plant.

Care in Drying

38. All types of linings must be dried out carefully, and especially the plastic type. Air drying (where warm air is available) for two to three days is recommended for the plastics, and at least one day is necessary for block linings. A slow wood or charcoal fire may then follow, gradually increasing for two days before preheating with the furnace blast.

39. A second coat of refractory cement is desirable after preheating and before charging. It must be remembered that all moisture from the plastic must be expelled through the mass itself. Careful drying and venting therefore is necessary. The thicker the lining, the more venting will be required.

40. The wisdom of using the plastic material in the dryest possible condition in which it can be rammed will be appreciated. This feature reduces the total amount of shrinkage of the lining on drying, which is a desirable feature in maintaining the strength and ultimate life of such a lining. However, the mistake of having the material too dry is encountered more often than the reverse. The average super-refractory plastic requires

about 10 per cent of moisture, while some of the fireclay mixtures go up to 25 per cent.

GLAZING LININGS

41. Before starting up the furnace, and often at times during the operation, it is advisable to coat the inside of the lining with a glaze to assist in the prevention of metal seepage and, in the case of silicon-carbide linings, to prevent possibilities of metal contamination.

42. It seems unusual to expect contamination from a refractory mineral such as silicon-carbide; however, this can easily be explained. It is questionable whether or not under certain conditions the actual mineral is dissociated; however, with certain metals this is probable.

43. Silicon-carbide crystals themselves as manufactured are coated in spots with metallic silicon. If this be removed chemically—as it is by most manufacturers—and the grain tested for surface silicon, it will usually give a negative result. However, when this same grain is broken up and again tested, a positive result is obtained. This is due to the silicon-carbide crystal being of a laminar type and having occluded metallic silicon particles.

44. It is a curious fact that the same net metal contamination can be attained by the mixture of foundry sand (adhering to gates and sprues) and oily borings and turnings. It is obvious, therefore, that the blame is often wrongly placed.

45. A well-glazed lining, in which the silicon-carbide crystals are protected by the glaze from the attack by lead, will run for long periods of time without the slightest sign of trouble.

46. These points are brought up to show the necessity for glazing. It is naturally easier to glaze the lining of an open-flame furnace than most any other type. Various materials are used, such as common salt, fluorspar, barium sulphate, soda ash and glass. Some of the prepared brass cleaners give a good glaze and are not as hard on the lining as the materials above mentioned.

47. During the life of the lining, should the glaze scale off or be punctured for any reason, it is advisable to reglaze at once.

SUMMARY

48. During the normal operation of the open-flame furnace, perhaps the greatest aid to rapid destruction of the lining is

metal seepage. This is particularly true of metals having high lead content. When superheated, these metals become very fluid, easily finding small cracks and pores.

49. Thin sheets of lead alloys and similar low melting point mixtures are frequently found against the steel shell of the furnace when the lining is torn out. Maintaining a well-patched, well-glazed lining will help prevent this trouble.

Factors Conducive to Long Lining Life

50. It might be well to summarize the factors conducive to long lining life. These are:

(1) Install properly.
(2) Preheat thoroughly.
(3) Glaze before using.
(4) Inspect lining daily.
(5) Hot patch where necessary.
(6) Cold patch weekly.
(7) Use mild cleaner to remove accumulated slag.
(8) Rotate furnaces (of this type) properly.

51. When lining plus patching cost per ton—taking into account increased fuel cost due to age and condition of lining—cause total melting costs to increase, it is time to retire the lining.

52. The accompanying paper on refractory cements goes into full details regarding the question of lining maintenance and the economical limit of lining life, so that it will be unnecessary to discuss it further here. (See Preprint 30-23.)

53. The importance of keeping accurate records, both of lining installation costs, patching materials plus labor cost, other furnace maintenance and energy consumption cost, cannot be stressed too much.

NONFERROUS CUPOLAS

54. At the 1924 meeting of the A. F. A., T. F. Jennings presented a paper[2] on making copper castings from cupola melted metal. This procedure was a war-time necessity, but of late interest in this type of melting has been renewed and a few cupola installations are replacing open-flame furnaces for some classes of work.

55. Jennings used an ordinary No. 3 Whiting cupola lined

[2] *Making Copper Castings from Cupola-Melted Metal.* TRANS., A. F. A., vol. 32, pt. 1, pp. 205-210 (1924).

with silica brick of standard sizes. A mixture of 50 per cent silica sand and 50 per cent fireclay was used to lay up the brick and for patching and repairing in the melting zone.

56. The sand bottom was made the same as for an iron heat or for melting all steel in the cupola. The operation did not have as injurious an effect on the cupola lining as a high per cent of steel in cast-iron mixtures. A reduced blast pressure was used which had considerable influence on not burning out the melting zone.

57. The advocates of this type of melting are recommending silicon-carbide refractories for the melting zone. Out of 25 installations in the 14 foundries investigated, all but three are using silicon-carbide refractories and cements, even when melting high lead metal mixtures.

58. Some mullite-type linings have been tried, and while these did not fail, slag built up against them, causing bridging and cutting off of the blast in the cupola. The application of the proper type of flux might overcome this trouble. High-alumina refractories also are being tried.

59. Some special block linings have been made for these cupolas, but it is apparent that standard arch brick are much more satisfactory and will give better service. They are much more dense, due to being machine made, and naturally lend themselves admirably to fitting the tubular shape of the cupola shell.

60. This type of melting in its rejuvenated form is too new to obtain data on lining life and maintenance practice. Lining life of three weeks to six months, operating on day shift only, has been reported.

61. One precautionary measure has been brought out which also applies to ferrous melting. Upon dropping the cupola bed plate after the day's run, it is advisable to rake the incandescent coke and slag away from under the cupola before quenching, if this be necessary. The resulting water vapor will then not come in contact with the hot refractory lining, and it will be preserved from the probability of spalling action.

(Discussion of the preceding paper is combined with that of the following paper, and will be found on page 665)

Refractory-Maintenance Cements in the Nonferrous Foundry*

By H. E. White,** Pittsburgh

Abstract

The desired properties of refractory cements are said to be elasticity; mechanical strength; high softening point; resistance to abrasion; low shrinkage; resistance to disintegration, slagging and spalling; long vitrification range, and workability. Specifications, if furnished, would be of considerable assistance in securing proper material; data for such specifications are given. Some 49 different brands of cements were studied in the preparation of this report. These are discussed under such groups as fireclay-silica ganister, silicon-carbide, alumina and alumina-silica, and kaolin-clay combinations. Data secured in 1926 and 1929 are compared, and these show that the so-called super-refractories are on the increase. Application of the different cements to various uses are discussed.

Introduction

1. Refractory cements have been misrepresented and misused for so many years that mere mention of them frequently provokes the title "hokum." It is well to state this at the outset as it is hoped to help clear up misunderstandings through the medium of this paper and relieve these products of this odious appellation.

2. Melting, or more properly, P. C. E. (pyrometric cone equivalent) points, have been the most generally accepted tests of cements from the manufacturers' viewpoint, while what the foundryman wants to know is, will it stick to the old lining and stay put, and how long? Unfortunately, a good many of the average foundryman's ideas are difficult to translate into technical tests, but quite a little work is being done in this direction.

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*Prepared by the author under the sponsorship of the Nonferrous Survey Sub-Committee of the Joint Committee on Foundry Refractories.

**Lava Crucible Co. of Pittsburgh.

Desired Properties

3. A brief technical outline of the desired properties in refractory cements is as follows:

(a) *Elasticity,* or ability to adapt itself and cling to unlike materials having different coefficients of expansion.

(b) *Mechanical strength* to maintain loads at high temperatures and not crumble or bloat.

(c) *High P. C. E.* (softening point).

(d) *Resistance to abrasion.*

(e) *Low shrinkage.*

(f) *Resistance to disintegration*—low porosity to prevent dissociation by gases.

(g) *Chemical resistance* (slagging).

(h) *Resistance to spalling.*

(i) *Long vitrification range.*

(j) *Workability.*

4. Confinement of heat is a minor item with most refractory cements when used for maintenance only, but must be considered when used on new work as a bonding mortar, or when used for the entire structure as a semi-plastic ram. It has come to the point where refractory cement manufacturers are forced to give more definite data regarding their products. The ultimate consumer wants this information in practical language.

Some Factors for Specifications

5. The following specifications, if furnished by the manufacturer or, better, by some authorized laboratory, would be of considerable assistance:

(1) Lowest temperature at which there is sufficient bonding action to hold the patch in place.

(2) Temperature at which cement will flow under slight pressure.

(3) If it is an air-set cement, at what temperature will the temporary bond disintegrate?

(4) Thermal conductivity in reference to firebrick.

(5) Weight per cubic inch, dry and fired.

(6) Per cent shrinkage.

(7) Thickness of patch recommended for proper drying and firing.

(8) Percentage of water contained.

(9) Approximate chemical composition.

(10) To what class of refractory structures, metal, slag conditions and fuels is this cement adapted?

(11) At what temperature does vitrification start and when does over-vitrification begin?

TYPES AND PROPERTIES OF REFRACTORY CEMENTS AVAILABLE

6. During the investigation leading to the writing of this paper, 49 different brands of cements were examined and analyzed. These will be discussed in their respective groups.

Fireclay-Silica Ganister Group

7. Twenty-one were of the fireclay-silica ganister and allied mixtures having a P. C. E. range in the neighborhood of 2600 to 2800 degs. Fahr. Some of the cheaper varieties have real merit. Others are simply mixtures of fireclay and crushed old brick, fireclay and sodium silicate, or silica sand and fireclay. The moisture content is as high as 50 per cent.

Silicon-Carbide Base Group

8. Ten were of silicon-carbide base. These appear to be the most developed. The base is either silicon-carbide grain or silicon-carbide firesand. Most have clay bonds, a few have clay plus secondary air-set bonds, and still fewer leave out the clay and use high-grade synthetic mineral bonds. The P. C. E. range on these samples was 2700 to 3400 degs. Fahr.

9. Silicon-carbide-base cements are characterized by their acid reaction, electrical conductivity and high thermal conductivity. At extreme temperatures, they react with most clays so that the synthetic bonded cements are recommended for the higher ranges. The resistance to abrasion of this type of cement, however, makes it applicable to many lower temperature operations.

10. These cements generally seem to have a greater elasticity than other super-refractory cements, and therefore are more applicable to varied refractory structures. Asbestos fibre, properly used and of good quality, enhances this property.

Alumina and Alumina-Silica Group

11. Alumina, alumina-silica and allied minerals, including those containing appreciable percentages of mullite, make up the third class. Ten of these types were investigated. Three of

these were of the electrically fused crystalline alumina type and represent the highest types of this class. They have relatively high thermal conductivity, but not as high as silicon-carbide. The natural bonding agents are extremely refractory and well-balanced clays. The price of all three of these classes is quite high.

Kaolin Group

12. Calcined kaolin, raw kaolin-clay combinations made up two of those examined; diaspore-clay, one; electric furnace mullite-clay, one, and converted cyanite, andalusite, sillimanite-clay combinations, three. These last seven are being developed rapidly.

13. They are fairly neutral to most slag and metal attack, are of intermediate thermal conductivity and are electrical insulators. There is no possibility of metal contamination from most of the cements of this class.

Chrome-Ore Base Group

14. Five chrome-ore-base cements were examined. Some of these were excellent, but some were evidently compounded with little apparent research. As a class, for nonferrous work, these cements cannot hope to take the place of other types and are confined mainly to ferrous work. This is due mainly to difficulty of bonding and internal mineral reactions, causing a softening of the bonded structure after continued use.

15. The remaining cements were of a special nature. The highly basic magnesia cements bonded with small percentages of chlorides of lime, or clay, or combinations of these, and zircon cements, complete the list.

TREND IN USE OF REFRACTORY CEMENTS

16. In compiling Table 1, showing the relative use of the various types of cements, the 1926 data covering 81 foundries was secured from the Joint Committee on Foundry Refractories, nonferrous survey, and the 1929 data taken from industrial service reports covering 190 foundries. It is curious that a few companies still continue without the use of maintenance cements.

17. The above table shows conclusively that the use of super-refractory cements is on the increase. Curiously enough, the figures for open-flame melting follow those for crucible melting.

18. These figures are merely on installations and are not weighted averages.

APPLICATION OF VARIOUS CEMENTS TO VARIOUS USES

19. What the ultimate consumer of refractory cements wants to know is, what to use for the various furnaces and melting conditions encountered in his foundry? The choice of cements depends upon mechanical and chemical requirements.

20. The use of fireclay and ganister types of cements is limited, of course, to the lower temperatures. The super-refractory cements of the various types must be selected for the higher temperature ranges.

Table 1

DATA* ON USE OF REFRACTORY CEMENTS

	Types of furnaces					
	Crucible furnaces.		Open-flame.		Electric.	
	No. Installations					
	45	138	39	39	29	40
	Year					
	1926	1929	1926	1929	1926	1929
	Percentages of Users					
Fireclay, ganister and allied cements not truly super-refractory	44.50	17.5	36	17.25	27.5	2.5
Silicon-carbide super-refractory cements	53.25	74.5	61.5	74.25	52	37.5
Aluminum-oxide, alumina-silica, mullite and allied super-refractory cements	2.25	3.5	2.5	2.75	20.5	57.5
Chrome-ore base	...	2.25	...	5.75	...	2.5
Unknown	...	2.25	...	...	...	...

*1926 data from nonferrous survey of Joint Committee on Foundry Refractories.

21. For crucible furnaces of all types, with the exception of the Northrup induction furnace, silicon-carbide cements have proven their worth and hold undisputed sway. They are easily applied and of long life.

22. Open-flame furnaces allow a wide selection of cements. Those of the aluminum-oxide, alumina-silica or mullite types are the most practical under average conditions. They seem to be harder to apply than the average silicon-carbide types, but give long life when properly used.

23. There is little difference between the application of cements in the open-flame furnace and the indirect or direct-arc electrics. Silicon-carbide cements may be used to good advantage in both of the above cases, but the conditions and application must be studied and must be under control of the operator.

Tendency to Spall Above Door

24. One distinct characteristic of nearly all types of refractories used in these furnaces, and particularly the electrics, is the tendency to spall just above the door. This section which is not glazed by the metal wash and which is overheated by the action of the electric arc is also the most rapidly cooled when the furnace is opened for charging. It is desirable, due to the above described tendency to spall, to provide a more open structure on the roof of the furnace. This is always the first place to patch, and the patch often lasts as long as the lining.

25. Silicon-carbide cements should not be used in contact with molten iron or fused iron salts, nor around electrical resistor wire. Other conditions permitting, a silicon-carbide cement should be chosen where rapid temperature changes are to be encountered. For use under strongly oxidizing conditions, aluminum-oxide or mullite cements should be chosen in preference to silicon-carbide cement. Aluminum-oxide cements are excellent for covering electrical resistor wires.

26. One of the most satisfactory uses for refractory cements is the setting of block linings of any type in the proper cement. Brick-lining life can be increased by using a super-refractory cement in this manner, and super-refractory linings will always last longer when set in the proper cement. In fact, most manufacturers of high-grade linings now furnish the proper cement with the lining, or specify the cement to be used.

Cements for Induction Furnaces

27. Considerable work has been done on cements for induction furnaces of the Ajax-Wyatt type. One manufacturer is partial to magnesite-spinel type, another to bonded chrome and still a third to aluminum-oxide types.

28. For this particular work it is necessary that a refractory be used in which vitrification will not take place under the working temperatures involved, so that the lining affected will not crack through its entire section. The refractory wears through, due to erosion by moving metal and due to the penetration of molten metal into the cracks and pores. At the comparatively low temperatures required for yellow brass, the linings are quite reliable and long-lived.

29. The electric current passes through the metal in direct contact with the lining. It is obvious, then, that silicon-carbide

or other materials possessing high electrical conductivity cannot be used.

30. Any considerable proportion of lead in the alloy has a tendency to cause excessive penetration of metal into the lining, and such alloys destroy the lining rapidly. The applicability of the induction furnace to foundry work would be greatly increased if it could be furnished with a lining which would consistently resist penetration at temperatures above 2500 degs. Fahr. when used for melting red-brass alloys containing moderate percentages—say, five to ten per cent—of lead.

31. Chrome-ore plastic linings have been used in these furnaces when melting alloys of 90 per cent copper. The channel block is the weak part here. Many furnaces melting yellow brass use chrome-ore plastic linings for the chamber, and clay refractory for the channel block. Sintered magnesia compounds have been used similarly.

32. In the Northrup type of high-frequency induction furnace, crucible life is long and may be maintained almost indefinitely by the proper use of some cements, such as those which use aluminum-oxide, magnesia and zircon as a base. This feature makes this type of furnace appear very promising for future development, especially for foundry work.

Summary of Practice

33. The above information may be condensed as follows:

(1) Crucible tilting type furnaces using oil or gas are ideal applications for silicon-carbide types of refractory cements.

(2) Open-flame tilting, open-flame rotating, indirect-arc electric rocking or rotating and direct-arc electric furnaces may use cements of silicon-carbide, clay-diaspore or alumina-silica types. However, in using the silicon-carbide cements, certain precautions must be taken in that high-lead or high-tin mixtures have a tendency to dissociate this type of cement.

(3) Nonferrous-cupola-maintenance practice follows closely that of open-flame furnaces. Silicon-carbide and crystalline-alumina cements seem to be the most popular at present.

(4) Indirect resistance furnaces cannot use silicon-carbide cement, due to its conductivity; neither can this cement be used on induction furnaces. The latter are limited to aluminum-oxide, alumina-silica, mullite and chrome-ore types.

(5) Cements containing alkali silicates must not be used in contact with resistor wires.

PROPER USE OF REFRACTORY CEMENTS

34. The personal element, with respect to the installation and maintenance of linings and the operation of furnaces, is of prime importance. Variations in this respect are frequently so great as to obscure the effect of all other factors governing lining life.

35. Patching linings is an art. It is next to impossible to give definite instruction covering its technique. It can be said, however, that frequent inspection and patching is of utmost importance.

36. In the case of hearth-type furnace linings, these should be inspected daily and every sign of incipient failure should be corrected by hot patching. Cold patching should be practiced once a week.

37. There are a multitude of patching cements on the market, and most of them are good when properly used. Some require more skill in their application than others. A suitable patch is one which will "stay put" indefinitely and will possess all of the good qualities of the original refractory. Making it "stay put" is the real problem.

38. For plastic use, add water sparingly, mix thoroughly and apply to moistened surfaces. For tamping, add water sparingly until a sample after thorough mixing will hold together when firmly compressed in the hand. No free moisture should be evident. It is well to riddle or screen the dampened mixture before using, and to prevent undue drying by covering with damp cloths.

39. The finer-grained mixtures shrink more than coarser ones from the plastic mix to the dry state. Minimum shrinkage follows the use of the smallest per cent of water in mixing. Plastic mixtures should be applied to moistened surfaces; slicking or smoothing surface with a trowel is considered good practice for either type of mixture. Tamping mixtures should be roughened between each two successive layers, in order to eliminate seams or joints.

40. Great care should be taken to dry the plastic or wetter mixtures thoroughly before firing. This is true also with tamped mixtures in cases where drying takes place mainly from one surface. Generally, unused dried-out material can be pulverized and remixed with water without any loss of refractory value.

41. Experience has shown that a slush coat of cement,

applied with a wide brush or broom, adheres and becomes a part of the wall or arch, whereas a coat which is plastered on has a strong tendency to peel. If a coating is to be applied to old work, all the loose dust and fly ash must be brushed off and the old clinker preferably cleaned off before the brush coat is applied. Where a cement gun is available, the coating may be applied much more rapidly than by hand.

42. At least two thin coats should be applied by either

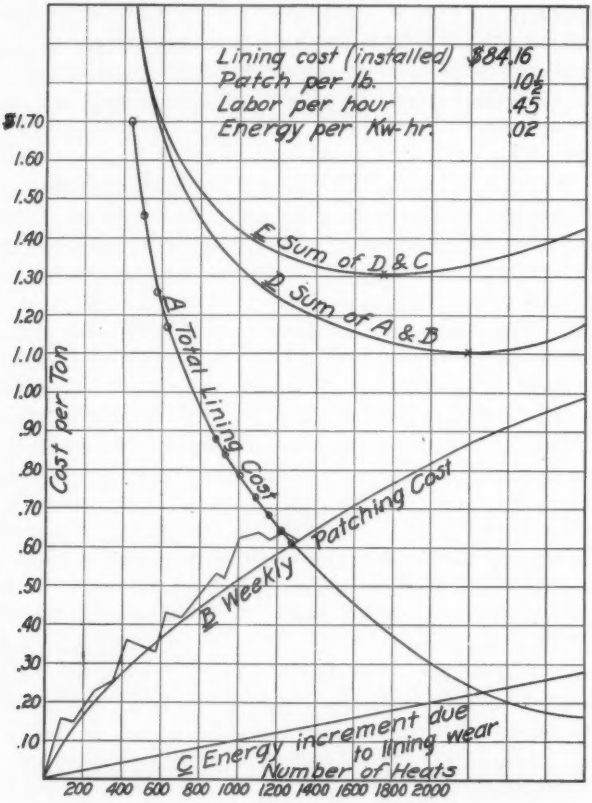

FIG. 1—CURVES FOR COMPUTING ECONOMICAL LIMITS OF FURNACE-LINING MAINTENANCE. AS LINING GETS OLDER, MORE ENERGY IS REQUIRED TO MELT SAME AMOUNT OF METAL—PLOTTED ON CURVE *C* AS A CONSERVATIVE 3 PER CENT INCREASE. OTHER CONDITIONS BEING EQUAL, MOST ECONOMICAL POINT FOR LINING RENEWAL IS FLAT PART OF CURVE *D*, THE SUM OF CURVES *A* AND *B*.

method. Two thin coats are much more effective than one thick one. When a cement gun is used to apply a coating to hot walls, it is much more effective to apply thin coats frequently than to wait until the wall is badly worn and then try to build up a thick coating in one operation. Frequent application of thin coats often will maintain the wall or arch for long periods without major repairs.

43. It must be remembered at all times that refractory cements are compounded to present as dense a surface to attack as possible. However, when the cement is applied, the face is heated first and, therefore, all the moisture and volatile constituents naturally must be driven from the main mass of the cement through the already partially vitrified face. Is it any wonder that thick patches frequently pop off?

ECONOMICAL LIMIT OF LINING MAINTENANCE

44. It often is a problem when to stop patching and reline the furnace. The accompanying curves of Fig. 1, based on actual foundry data and extended for purposes of illustration, will assist somewhat in arriving at this decision.

45. It is apparent at first that, where the patching cost curve *A* crosses the lining cost curve *B*, something should be done. However, further analysis will show that the sum of these two items is still on the decrease after this junction has been reached as illustrated by curve *D*, and that it is economical to continue patching the old lining. However, curve *D* begins to ascend after a time, and the patching plus lining cost increases.

46. Other conditions being equal, the most economical point for lining retirement is the flat part of the curve. The older a lining gets, however, the more energy is required to melt the same amount of metal, whether the energy be supplied as electrical, solid or liquid fuel. The reason for this is due to a number of causes.

How Lining Life Affects Power Costs

47. The lining wears thin and the heat conduction is greater. Metal seepage and the breaking down of heat insulation brings about the same condition. An increase of 3 per cent is conservative, and curve *C*, which is a straight line, has been plotted to represent this.

48. Adding curve *C* to curve *D* gives curve *E* and brings the critical range back somewhat on the abcissa. There are other

factors which will draw this point still further along, such as enlarged electrode ports on electrical furnaces and eroded combustion chambers on liquid or gaseous fuel-fired furnaces. These points, however, are limited to the particular installation.

49. By following this set of curves, lining quality and cement quality can readily be established and the cost of the more expensive materials easily qualified. The value of particular cements for different conditions also can be conveniently worked out.

NONFERROUS CUPOLA PRACTICE

50. A type of melting rather well established in other foundry fields—but heretofore considered inapplicable to the nonferrous industry—is coming to the fore in an endeavor to cheapen melting costs. This refers to the use of cupolas operating under low blast pressure for melting nonferrous metals.

51. The use of cements for this purpose has for the present been limited to silicon-carbide and crystalline-alumina cements. Fourteen foundries were investigated, representing 25 installations. Twenty-two of these installations used silicon-carbide cements, two used crystalline-alumina, and the twenty-fifth used sillimanite.

52. Some of these foundries use plastic refractories over the bed plate instead of the usual sand mixture used in iron-melting cupolas. This is to preclude any silicon contamination. One complete plastic refractory lining has been recorded.

CONCLUSIONS

53. In conclusion, the following points dealing with the proper use of refractory cements in the nonferrous foundry cannot be emphasized too strongly:

(1) Survey and carefully analyze the problem. Ascertain the chemical reactions involved and the physical obstacles to be met.

(2) Select the proper cement (or cements) for the use. Call in a service man; they are only too willing to help you.

(3) Prepare the structure to be built, repaired or patched.

(4) Properly prepare the cement for the various applications. (More than one consistency often is required.)

(5) Apply the cement properly and dry out thoroughly before applying heat.

(6) Maintain installation constantly—it will repay you by greatly increased life.

(7) Keep accurate records.

(8) When lining plus patching cost per ton—taking into account increased energy cost per ton due to age and condition of lining—cause total melting costs to increase, it is time to retire the lining.

ACKNOWLEDGMENT

54. The author wishes to acknowledge his indebtedness to H. M. St. John, chairman of the Sub-Committee on Nonferrous Survey of the Joint Committee on Foundry Refractories, for assistance rendered in preparing this paper, and to C. H. Morken, Detroit Electric Furnace Co., Detroit.

DISCUSSION

ORAL DISCUSSION

H. M. ST. JOHN:* The Committee on Nonferrous Survey, a subcommittee of the Joint Committee on Foundry Refractories, is following the policy of collecting information from the nonferrous foundries as to the refractories they are actually using and the experience they are having with them, at the same time keeping in touch with the refractory manufacturers so that the committee can be up-to-date at all times on improvements in refractories. By means of such papers as this it then brings this information to the attention of the foundrymen. It is the thought of the committee that in this way we can be of maximum service to the industry.

At the same time, we want it thoroughly understood that we want suggestions. If there is anything the committee can do for the foundrymen that it is not doing at the present time, we would like to hear about it. And, if it can be done, we will certainly be glad to do it.

In opening the discussion of this paper, there are several points that I would like to emphasize as a basis for discussion.

When the work of the committee was started and the original survey was made, the most striking thing we learned was the great difference in experience with refractories in different foundries, where the same types of furnaces were used under much the same conditions. We found some foundries were getting much longer life than others, their refractory cost being less and, naturally, the interference with production being less also.

Thus, one of the first things the committee tried to do in the report

*Detroit Lubricator Co., Detroit.

made in 1926 was to call attention to and emphasize the fact that many foundries were falling far short in refractory performance of what they might be able to do, and that this was really an important cost element. It seemed that foundries were inclined to consider refractories as a necessary evil, and that if they failed, why, they just failed, that was all, and the furnaces had to be relined. Some foundries using each class of furnace considered were getting quite phenomenal life as compared with the general average.

In this last paper by Mr. White, another point has been emphasized and that is that lining life can be overdone. Mr. White is to be congratulated not only on the amount of study that he has put on these various experiments, bringing out a paper that I think presents entirely new information to the general foundry industry, but also in the working up of these curves which show the economical life of the lining. In many cases, while it is possible to continue operating your furnaces with the lining apparently in good condition and requiring only a reasonable amount of patching, the lining life is carried beyond the low point on the curve, as shown in Fig. 1. The curve is really rising, the cost of refractory maintenance per ton of metal is increasing week by week and the foundryman never knows it.

We may have originally encouraged the individual foundryman to increase his lining life, by emphasizing the fact that some were getting much longer lining life than others, past the economical point. And, in bringing out these curves, I think Mr. White has demonstrated very well that there is an economical point which, of course, will vary from one foundry to another and should be considered. He has mentioned the fact that there are one or two more or less intangible factors that would tend to move the low point on the curve still farther to the left.

There is another factor which he did not mention specifically and which would tend to move it farther to the right—that is the loss in production; the loss in furnace time for relining. In general, the factors which have been considered in drawing up these curves should be the basis for determining economical lining life. As the cost of the refractory materials in common use increases, as is obviously the case from the results of this survey, then the importance of paying more attention to refractories becomes more marked, because the refractories are costing more money. And if we do not use them economically, the cost per ton of metal melted will rise.

C. H. MORKEN:* Mr. White has presented in a very comprehensive manner a subject to which I have given considerable thought and which, during the course of the last month or so, I have had occasion to discuss with a great many foundrymen scattered about the country. The text of the paper should serve two purposes, I believe. For one thing, it should stimulate more analytical research into refractory linings for nonferrous maintenance.

I think the average foundryman is rather prone to select his patches or his original linings more or less "by guess and by gosh," without

*Detroit Electric Furnace Co., Detroit.

giving any thought to the ultimate cost per ton of metal melted. I really believe that this is going to be the starting point for the selection of the proper refractory for each founder's needs.

We have also, of course, the means here of determining at all times exactly what your lining or your total refractory cost is. It is interesting to note that this method reveals some other things.

In the first place, it will draw a very fine distinction between two furnace operators. I have one case particularly in mind of a furnace that is running on iron where one operator was discharged because he could not keep his curves as low as the other operator, at first thought to be due to carelessness and later so proven. In other words, he did not ram his patches in, or he did not take particular pains to dovetail the patch in and give it secure anchorage and, as a result, his patching cost kept going up more rapidly than it should have.

Another thing that can be brought out very easily is faulty ceramics. We may get a lining that has a lot of curing checks in it in such a location as to spall out unduly easily. That will show in patching required during the first two or three weeks of operation.

The cost per pound of patch will have a great deal of bearing upon the tangent of the curve representing the patching cost. The ordinary patches that you buy will run perhaps five or six cents a pound. When you get into the more expensive patches that a good many men hesitate to use, they may cost ten, eleven, or maybe twelve cents a pound delivered at your plant. We have frequently found that the twelve-cent patch is cheaper than the five-cent patch and gives better service from the point of view of continuity of operation.

Also, the cost of lining determines the nature of the slope of the *A* curve. The more expensive the lining, the more the first few weeks are going to cost in dollars per ton of metal melted. However, the ultimate will be, of course, the sum of the two curves, and from that point it is very easy to determine whether your more expensive lining is ultimately cheaper than the cheaper lining, and likewise with the patch.

The one thing, of course, that the curves do not show—which is, to my mind, rather vital in foundry operation—is continuity of operation. In other words, you may reach a condition where the summation curve, the *D* curve, is showing a decreasing value week by week, and still mid-week delays would make it advisable to yank the lining and put in a new one—or mid-day delays, perhaps I should say, because of the fact that most patches are not applicable to the hot furnace.

I would like also to call attention to the fact that the *B* curve, or the weekly patch curve, should include material and the labor expended in order to present a fair picture.

W. F. GRAHAM:* With regard to the data and curves presented in Mr. White's paper, when Mr. Morken gave me these figures some time last year, I admit that I was more or less skeptical as to the value of the method of forecasting the life of the lining. During the past twelve months or so I have become more or less convinced that it is a very desirable method of checking.

*Ohio Brass Co., Mansfield, Ohio.

WRITTEN DISCUSSION

R. W. PARSONS: *Mr. White's paper should be of considerable value to those in the nonferrous foundry industry who are concerned with the selection and maintenance of refractories. As regards determining the economical lining life by means of the curves, which the author has presented, I should like to comment on the method of tabulation.

It was convenient to record the weekly patching cost (labor and material) and the tonnage to date at the same time. This means that the cost of preparing the furnace for next week's operation was charged to last week's tonnage, which, of course, is inaccurate. The true curve is slightly below, and roughly parallel to, the curve *B* shown by the author. As a result, the tonnage for the last week of operation was added to the total without a similar increase in the total patching cost.

*Ohio Brass Co., Mansfield, Ohio.

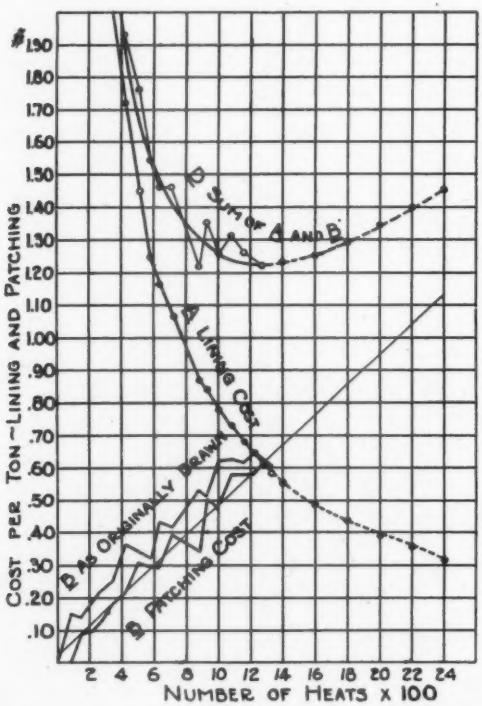

FIG. 2—LINING-COST CURVE FOR 250-LB. INDIRECT-ARC FURNACE. LINING COST (INSTALLED), $84.16. PATCHING MATERIAL AT 10.5 CENTS PER LB. LABOR (PATCHING) AT 45 CENTS PER HOUR. CURVE *A* WAS EXTENDED ON THE BASIS OF AN AVERAGE OF 216 LBS. PER HEAT.

Thus the curve *B* takes a sharp drop for the final week. This drop (or perhaps lack of increase) during the last week is also observed on the true curve, because the lining is not repaired so thoroughly when it is known that the furnace is to be relined at the end of the week.

Let us discount, then, the final point and, in the case of the true curve, draw a straight line through the second point, the point at 1000 heats and the point of intersection (See Fig. 2). A study of a number of these curves indicates that the straight line assumption is not unreasonable—certainly it does not appear reasonable that less maintenance will be required as the lining life increases—that is, within the limits with which we are working, as is indicated by the curve *B* which the writer has presented.

The extension of the lining cost curve *A* as shown by the writer is unlike the curve which would be obtained if values were plotted for 2,200 heats of exactly 250 lbs. each. The average charge during the life of this lining was 216 lbs., and if the curve is extended on this basis the value at 2,200 heats will be 35c instead of 25c as shown. Whatever the value of the average charge, the curves will be parallel— *A to* A_2 where *A* is for 219-lb. heats and A_2 for 250-lb. heats).

With the curves *A* and *B* adjusted according to the above (Fig. 2), it is seen that their combined value (total cost) is a minimum at the point of intersection, and increases with the number of heats beyond the point of intersection.

Even if a slightly lower cost could be shown at 2,200 heats, there is no assurance that the patching requirements are not liable to increase sharply at some point between 1,300 and 2,200 heats, and thus wipe out the small margin that might exist in the way of a saving. To gamble for such slight differences, as might be shown, would seem unprofitable when we consider that the furnace might become unusable in the middle of the week, with costly delays as a result.

It would even be economy to install a new lining prior to the point of intersection if it appeared that the furnace was in such shape that it would require a great deal of expense to prepare it for the coming week. For instance, the combined cost—curve *D* Fig. 2—at 880 heats (with the adjusted curves) has the same value ($1.22) as it has at the point of intersection. At 1,000 heats the difference is four cents (for 150-ton lining it would amount to only $6.00) and the penalty, in case of an unsuccessful "gamble," can run into considerable money.

Mr. White has pointed out (paragraph 24) the tendency for spalling just above the door. When this happens and extensive patching becomes necessary early in the life of a lining, the patching cost curve obviously is altered. The result is a curve which attains an appreciable value very soon and proceeds at a much lower rate of increase for the remainder of the life of the lining. This is illustrated by Fig. 3.

With the above condition the total cost may be decreasing beyond the point of intersection, depending on how curve *B* is extended, but the difference is very slight if we assume that it exists. The very fact that extensive repairs are occasionally necessary (3rd point on curve *B*, Fig. 3) would seem to substantiate the arguments in the third preceeding para-

graph, for, if the circumstances which altered the character of the curve in the first place are repeated beyond the point of intersection, the total cost will be greatly increased.

Another curve for a different lining, Fig. 4, illustrates a case where it might be economy to patch the lining almost indefinitely, depending on the interpretation and the manner of extending the curves. In any event, it will be seen that the lining cost is decreasing very slowly, and any differences in the total cost will be very small.

Figs. 3 and 4 are for a furnace of 350-lb. capacity, while Fig. 2 is for a 250-lb. furnace. Curves for 750-lb. furnace of the same type are not available at this time, but the incomplete data indicates that the curves will be very similar to Fig. 2.

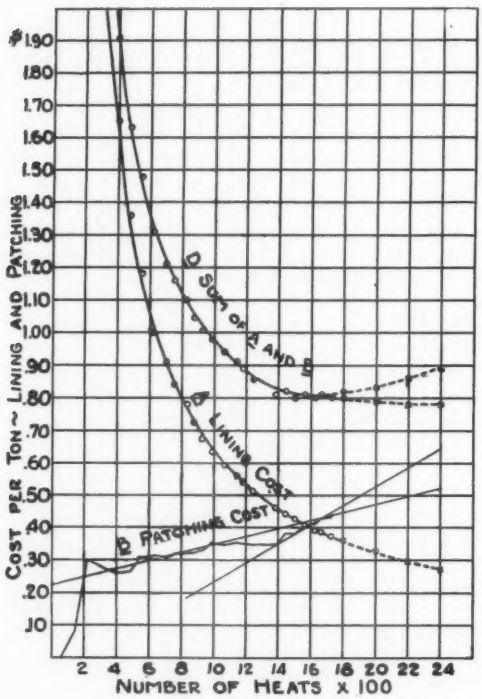

FIG. 3—LINING-COST CURVE FOR 350-LB. INDIRECT-ARC FURNACE. LINING COST (INSTALLED), $100.95. PATCHING MATERIAL AT 10.5 CENTS PER LB. LABOR (PATCHING) AT 45 CENTS PER HOUR. CURVE *A* WAS EXTENDED ON THE BASIS OF AN AVERAGE OF 311 LBS. PER HEAT.

REPLY BY AUTHOR

H. E. WHITE: These curves are applicable in general to any type of furnace. They were adjusted to facilitate illustration and to show more clearly the results that can be obtained by the use of curves.

Curve *A* is a function of the total lining cost including labor, and will maintain its general characteristics affected only slightly by the type of furnace and somewhat by the charge per heat. To curve *A* should be added the overhead, energy demand and other stand-by charges on the furnace while shut down for relining. This will tend to raise the horizon of curve *A* and bring the low point of *E* and *D* farther to the right.

In my opinion, curve *B* as shown in the original Fig. 1 should be left as it is, and not advanced as Mr. Parson has it. If left as originally shown, the cost of repairing or patching the furnace will be charged to the operations that did the damage. In other words, the metal melted

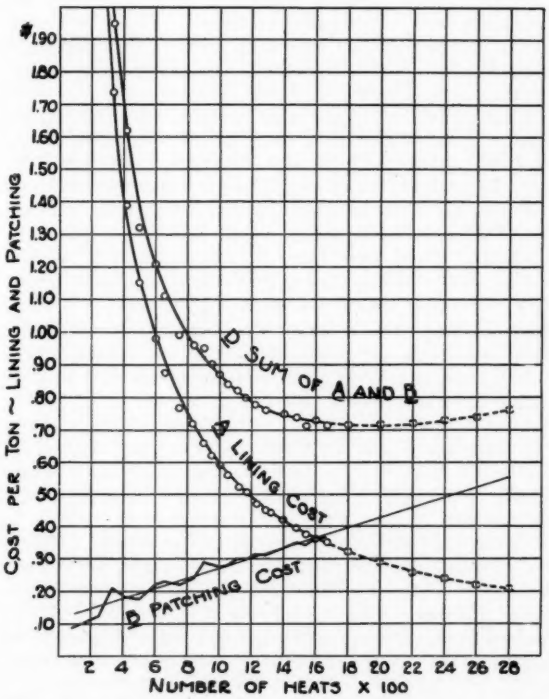

FIG. 4—LINING-COST CURVE FOR 350-LB. INDIRECT-ARC FURNACE. LINING COST (INSTALLED), $100.95 PATCHING MATERIAL AT 10.5 CENTS PER LB. LABOR (PATCHING) AT 45 CENTS PER HOUR. CURVE *A* WAS EXTENDED ON THE BASIS OF AN AVERAGE OF 343 LBS. PER HEAT. NO DATA ON PATCHING COST UP TO 79TH HEAT.

during one week will be charged with the maintenance necessary at the end of the week in order to put the furnace in shape for the next week's operations, and theoretically to renew the lining and make it as good as it was when new.

One basis for this argument may be where different kinds of metal are melted. Assuming that copper is melted this week and yellow brass next week, using the same lining, naturally there would be more maintenance on the copper operation which, according to Mr. Parson's method of figuring, would be charged to the yellow-brass operations. This procedure is not recommended, but merely given to illustrate the reasons for maintaining curve *B* as shown in Fig. 1.

The character of curve *B* may be closer to a straight line than shown, especially in its lower portion. However, this will depend upon the nature of the operation and on the type of equipment.

From a study of Mr. Parson's curves, they seem to ascend rapidly at first, sloping into a diagonal straight line and tipping toward the horizontal at the end. This shape of curve is probably typical for the furnace from which the data was taken, the sudden rise at the start being caused at times, as Mr. Parson remarks, by spalling above the door.

Open-flame furnaces with the door similarly placed probably would have a similar curve, while open-flame furnaces and electrics which pour and charge in a different manner probably will approach the curve of a crucible-furnace lining, being close to and very nearly parallel with the base line for several periods and rising more rapidly toward the end. This is best illustrated with a crucible-furnace lining which requires no patching for two or three thousands heats.

Discussion of the proper shape of curve *B* makes the total curves *D* and *E* even more valuable than at first imagined, and if curve *E* is used to indicate economical lining life, the shape of curve *B* is unimportant.

Toward the end, when the furnace is about to be relined, the *B* curves undoubtedly will slope off toward the horizontal, as there will be little economy in wasting expensive patch on a furnace when it is known that it is to be shut down to install a new lining.

To curve *B* should be added overhead and stand-by charges necessitated by shut-downs due to faulty patching practice, or shut-downs caused by lining trouble which can be repaired by maintenance cement. This is really a function of the patching cost. It will tend toward more thorough patching.

The figures used in curve *B* are cumulative figures. They represent the entire patching cost, including cement and labor, divided by the total tonnage produced. They are calculated for each period and plotted against the number of heats.

In regard to curve *C*, too little attention has been paid to the energy-increment curve. The low point of curve *E* depends upon curve *C* for its location.

It is hoped that this discussion will stimulate the keeping of data not only on electric furnaces but on gas- and oil-fired open-flame and crucible furnaces, so that it will be possible to obtain a complete set of such curves for each type of furnace in the nonferrous industry.

The Correlation of Mechanical Tests for Cast Iron*

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Abstract

The author reviews recent work carried out in Great Britain, particularly by the British Cast Iron Research Association, on relations between mechanical tests for cast iron. Since mechanical properties are governed by structure, it is shown that conditions of melting have a profound influence on the structure and, hence, the properties of certain irons, in addition to composition and rate of cooling. This influence is so pronounced that it transcends minor differences in composition and section. Cast irons may crystallize in one of two types of structure: Pearlite (normal graphite, which may present a wide degree of variation in graphite size) and ferrite (fine graphite, presenting a much narrower range of variation of graphite size). These two types of structure, which may occur in the same iron, present different combined carbon contents, mechanical properties and chilling tendencies. These differences can be produced in irons of the same composition by appropriate variations in the melting conditions. Skin-machining improves mechanical test results, while further removal of stock diminishes them. The strength of a series of bars cast at different diameters may be taken either on skin-machined bars (as for transverse) or may be machined to a constant diameter (as for compression or fatigue testing). In both cases, the strength varies continuously with cast section, but in the latter case the strength is relatively weaker throughout than in the former. In determining change of strength with section it is advantageous to express the transverse strength not as breaking load but as load per square inch of section, as in tensile and other mechanical tests. The strength of a series of bars cast from the same ladle (i.e., same composition and conditions of melting) varies continuously with transverse, tensile or com-

*Exchange paper of the Institute of British Foundrymen.

**Director and Secretary, British Cast Iron Research Association.

pression strength — the strength increases as the section diminishes, within the gray range. The strength also varies continuously with composition (silicon content)—it increases as silicon diminishes within the gray range. These changes cannot be represented by a simple physical law. Bars cast under a variety of melting conditions show a considerable degree of scatter, even for the same section and silicon content. The adoption by Great Britain, the United States and Germany of the 1.2-inch diameter round bar offers opportunities of comparison of results on an international basis. Tensile, transverse and compression tests appear to measure the same basic property of cast iron, for they vary in sympathy and, under closely standardized testing conditions, have a fairly constant ratio to each other.

INTRODUCTION

1. The problem of adequate tests for cast iron is, perhaps, the greatest of the many problems that the foundry metallurgist has to face. It lies at the root not only of the buying and selling of castings, and of the control of manufacturing operations, but also of our research policies and programs. For, where castings are concerned, tests of quality, properly designed, conducted and interpreted, form the elements of our metallurgical vocabulary.

2. This paper will deal mainly with the mechanical tests usually specified by the engineering buyer and with the translation, as far as at present practicable, from one form of mechanical test to another.

Renaissance of Cast Iron

3. At a time when we are witnessing a veritable renaissance of cast iron as a metallurgical material, such correlation is calculated to reduce the time and expense involved in testing and to promote proper standardization of testing procedures. It should also help to convince the engineering designer of the great economies that can be effected by the rational design of castings and by full cooperation between designer, foundry engineer and metallurgist.

4. The need for a high factor of safety in cast-iron design arises not only from unexpected stresses and possible lack of homogeneity, but from uncertainty arising from lack of relationship between test bar and casting. The consequences of mistesting are always against the founder.

CRITERIA OF QUALITY OF CAST IRON

5. What is the most satisfactory criterion of the quality of that wide series of heterogeneous crystalline aggregates which we call cast iron?

6. The founder, the chemist, the physicist, the metallurgist and the engineer do not at present agree on what property or quality of cast iron best forms a basis for its consideration. The chemist favors analysis, the ultimate composition of the metal being incontrovertible—and, indeed, it gives valuable information which can be obtained in no other way.

7. Commercial analysis, however, does not usually include elements other than carbon, silicon, manganese, phosphorus, and sulphur, the so-called rare elements, gases, etc., being omitted. Thus a tendency arises to ascribe anomalies of behavior to these undetermined elements, or (more commonly), to criticize the chemist's work quite undeservedly because conventional analysis does not, and indeed cannot, explain these anomalies. Chemical analysis, moreover, does not indicate the manner in which the elements of composition are combined.

8. The physicist can associate changes of quality with changes in density, in thermal, electrical or magnetic properties, but the correlations are not yet sufficiently well known to enable these properties to be used in specifications.

Importance of Micro-Examination

9. The metallurgist, of course, knows that the strength properties so important to the engineer are determined primarily by structure, which is not wholly determined by composition, or even by composition and rate of cooling—as will subsequently be shown—but which is the resultant of all the forces at work. He therefore leans toward microscopic examination, and the microscope indeed gives important information not only about general structure but also about its variation from point to point in the section.

10. It shows the distribution of compounds as they exist, but apart from the inability of the microscope to show directly the elements in solution—silicon, manganese, aluminum, nickel, chromium—it is impracticable as a routine acceptance test because any given examination is highly localized and the technique of polishing and etching is not very generally known.

11. The founder naturally looks to some form of fracture

test, preferably of a type which will yield a result before the casting is actually made, such as a chill test. The hitherto unresolved connection between composition and structure to be referred to below suggests that analysis should always be accompanied by some form of fracture test, microscopic or macroscopic.

12. The fracture test is sound for the same reason that the micro-examination is sound; but it is, of course, far less sensitive. It is logical because metal for many castings, which it would be impossible to judge by a purely mechanical test (such as for chilled rolls), can be judged satisfactorily by a combined fracture and chill test. Keep's test, in fact, which incorporates a chill test, is still used in some British foundries.

13. So much depends, however, on the size of the casting, its purpose and composition, that a standard chill test is impracticable, and there is as yet no agreement on suitable form, quite apart from size. Most foundries using the test work out a chill test empirically to suit their range of work. This duly integrates all the factors at work, and it is in this sum that the foundryman is really interested.

Variation in Behavior of Cast Irons

14. The practical founder is aware, of course, of unexpected and unpredictable variations in the behavior of cast irons of the same composition. This has recently been confirmed in an interesting manner in some work done by the British Cast Iron Research Association.[1] *

15. Figs. 1 to 4, inclusive, show synthetic cast irons, crucible melted, each at the same magnification. Fig. 2 shows the normal structure of pearlite and graphite found in ordinary engineering irons.

16. Fig. 1 shows a structure consisting of fine or supercooled graphite and ferrite of a kind which has occasionally been produced by superheating cast iron. The structure in Fig. 1 did not obtain over the whole of the bar, but existed in substantial quantities in the normal pearlite-graphite structure.

17. These two irons were virtually of the same composition (see Table 1) and cast in bars of the same size. The factors of composition and rate of cooling, therefore, were constant. The

*Reference numbers correspond with items in the Bibliography appearing at the conclusion of this paper.

differences in structure are due to differences (accidental or designed) in melting conditions, which have been demonstrated to have profound influences on the product and which formally introduce a third great influence on properties, unforeseen changes which are capable of explaining many of the anomalies of behavior from which cast iron suffers.

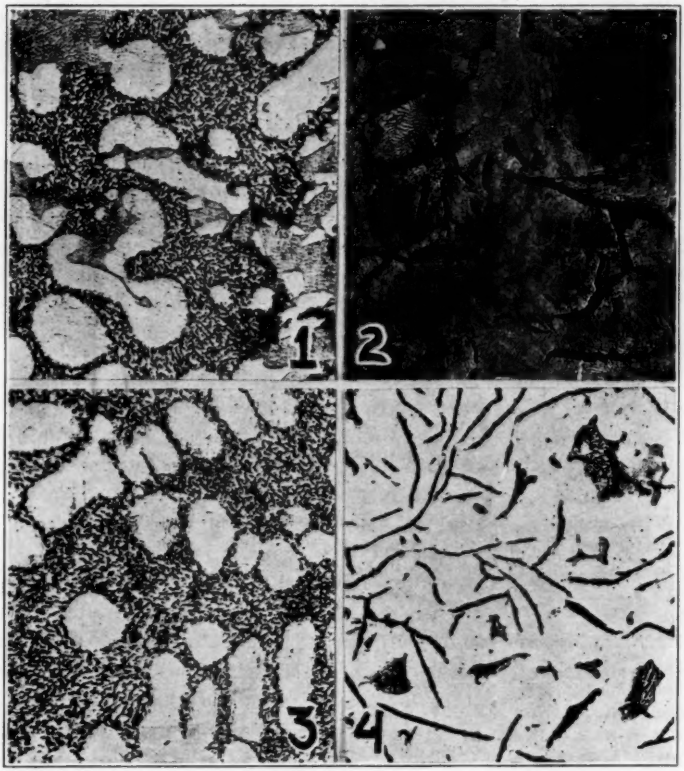

FIG. 1—GRAY CAST IRON. MEDIUM SILICON. 200X. (COMPOSITION SIMILAR TO FIG. 2)

FIG. 2—GRAY CAST IRON. MEDIUM SILICON. 200X. (COMPOSITION SIMILAR TO FIG. 1)

FIG. 3—GRAY CAST IRON. HIGH SILICON. 200X. (COMPOSITION SIMILAR TO FIG. 4)

FIG. 4—GRAY CAST IRON. HIGH SILICON. 200X. (COMPOSITION SIMILAR TO FIG. 3)

18. The present purpose is served by demonstrating these differences without discussing the reasons for them. It suffices to say that Dr. Norbury has evolved a theory to explain why graphite flakes below a certain critical size become associated with ferrite rather than with pearlite, and above this size pearlite may be associated with every size of graphite up to the coarsest obtainable from a given size of section and composition.

19. Most of the observations made on these irons can be explained tentatively by assuming that the irons crystallizing in the ferrite (fine graphite) system are initially free from graphite nuclei, and that irons crystallizing in the pearlite (normal graphite) system are not free.

20. In the former case the melt is super-cooled and the graphite appears spontaneously throughout the mass in the "labile shower" of the crystallographers, while in the latter case the flakes build up on the existing and never completely dissolved nuclei, flakes also joining others to form longer flakes. It has been possible to melt a pig iron and compel it to solidify in either system at will, according to whether nuclei were present or absent.[2]

Table 1

CHEMICAL ANALYSES

Reference.	T. C.	C. C. on 1.2 in. bar.	G. C. on 1.2 in. bar.	Si	Mn	S	P
Fig. 1	2.91	0.62	2.29	1.82	0.67	0.03	0.03
Fig. 2	2.94	0.80	2.14	1.70	1.00	0.03	0.03
Fig. 3	2.81	0.14	2.67	4.53	0.98	0.03	0.03
Fig. 4	2.71	0.17	2.54	4.46	1.10	0.03	0.30
Table 3, Iron A	3.2	1.00	2.20	1.37	0.94	0.09	0.18
Table 3, Iron B	3.5	1.02	2.48	0.98	1.01	0.09	0.21
Fig. 7, A, B, C	3.51	0.78	2.73	2.03	0.52	0.07	1.04
Fig. 8, A, B, C, D, E	3.53	1.04	2.49	1.03	0.35	0.11	0.40
Fig. 9 A, B, 17 A, B, C	3.57	...	...	1.58	0.52	0.10	0.65
Fig. 10 A	3.55	...	...	1.95	0.50	0.08	0.72
Fig. 10 B	3.71	...	...	1.29	0.62	0.09	0.59
Fig. 10 C	3.50	...	...	0.68	0.35	0.18	0.64
Fig. 16 A	2.89	...	...	1.88	0.99	0.10	0.23
Fig. 16 B	3.09	...	...	0.90	0.34	0.14	0.26
Fig. 16 C	3.46	...	...	1.57	0.45	0.10	0.43
Fig. 16 D	3.37	...	...	2.21	0.64	0.07	0.56

21. Figs. 3 and 4 similarly represent two structures from irons of similar composition, but higher in silicon than Figs. 1 and 2. Fig. 4 shows the usual ferrite (normal graphite) and Fig. 3, ferrite (fine graphite) as shown in Fig. 1. In this case the structure (Fig. 3) occupied the whole area of the bar.

22. A wide variety of mechanical tests have been made on irons of similar compositions in both systems.[2] There are practical difficulties in rendering an iron completely nucleus-free, and most of the irons containing ferrite (fine graphite) are mixed structures of this with pearlite (normal graphite—normal, that is, for the thickness of section and composition involved).

23. Irons composed wholly of pearlite (normal graphite) have high mechanical strengths. Irons wholly of ferrite (fine graphite) appear to have strengths comparable with those of the pearlitic irons, and, it may be noted, they are metallurgically stable.

24. An iron of mixed structure, however, is definitely weaker mechanically than an iron of either system alone. Tensile, transverse, repeated impact, brinell and machining hardness, and shear tests, all show that the mixed structures are weaker and softer than the all-pearlitic irons. The ferrite (fine graphite) iron is markedly darker to the eye and more sooty in appearance than the pearlite (normal graphite) iron, which has the usual gray, steely fracture.

25. The combined carbon content forms an index of the extent to which the structure is mixed. An all-pearlitic iron has the usual eutectoid percentage, while in an all-ferritic iron the value is very low. Mixed structures show intermediate values, according to the percentage of pearlite present.

26. These points are illustrated by Table 2, which gives the mechanical properties of the irons shown in Fig. 1.

Table 2

MECHANICAL TESTS ON IRONS (FIGS. 1-4, INCLUSIVE)

	Transverse, lbs. per sq. in. (1.2 in. bar)	Tensile, lbs. per sq. in. (1.2 in. bar)	Brinell (1.2 in. bar)	Repeated impact (0.875 in. bar)
Fig. 1	51,800	32,300	207	Mottled
Fig. 2	89,100	52,500	241	3,476
Fig. 3	77,500	44,000	235	235
Fig. 4	56,700	28,700	178	150

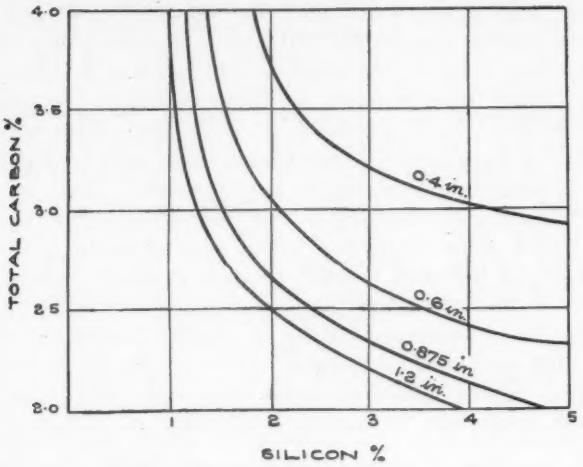

FIG. 5 — FERRITE (FINE-GRAPHITE) IRONS. LINES SEPARATING GRAY FROM WHITE AND MOTTLED IRONS IN SAND-CAST BARS OF STATED DIAMETERS AND COMPOSITIONS.

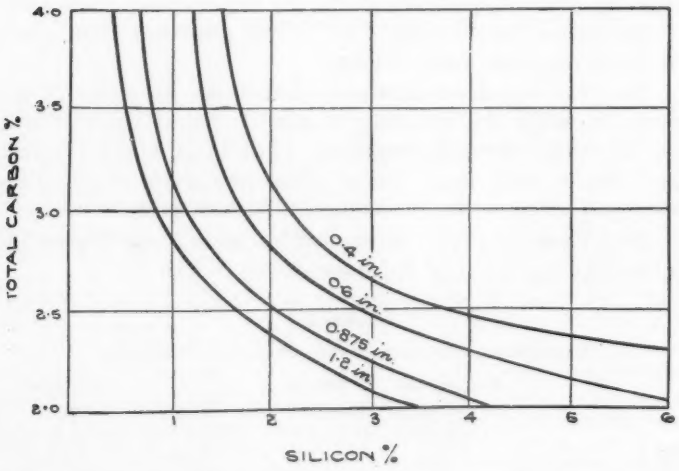

FIG. 6—PEARLITE (NORMAL-GRAPHITE) IRONS. LINES SEPARATING GRAY FROM WHITE AND MOTTLED IRONS IN SAND-CAST BARS OF STATED DIAMETERS AND COMPOSITIONS.

27. Table 2 shows the high strength of the usual pearlite (normal graphite) structure—Fig. 2—indicated by all the tests. Fig. 4, a higher silicon iron of similar graphite formation, is consistently weaker and softer, as would be expected. Fig. 3, wholly of ferrite (fine graphite), is of the same order as Fig. 2, the pearlite (normal graphite) iron, but is markedly weaker on impact.

28. Fig. 1, which should therefore be of the same order as Fig. 2, is low because the structure is mixed. Fig. 3 has a higher brinell hardness than Fig. 1 on account of the hardening effect of additional silicon in solution.

29. These broad differences are of great practical importance because, in the ordinary processes of manufacture, it appears to be difficult to get an all-ferritic (fine graphite) structure. However, in our experience, examples of mixed structures are repeatedly found in commercial pig irons and castings, and a number of cases of difficulty in practice have been found to be associated with this mixed structure.

30. Another most important difference is the fact that the ferrite (fine graphite) irons, in spite of their low combined carbon, are much more sensitive to chilling, as shown by Figs. 5 and 6. Thus a 1.2 in. bar with 3.0 per cent total carbon is just white with 0.85 per cent silicon, in the pearlite (normal graphite) system; while in the ferrite (fine graphite) system an iron with the same total carbon is white with no less than 1.3 per cent silicon.

31. Thus an iron which is liable to crystallize as ferrite (fine graphite) is much more liable to troubles associated with chilling. Cases of so-called "inverse chilling" often are nothing more than areas of white iron corresponding to the ferrite (fine graphite) system, surrounded by gray areas of pearlite (normal graphite).

32. The differences noted above between gray irons of similar composition are paralleled by differences between white irons of similar composition, in which—in the case corresponding to the super-cooled system—the eutectic is a fine dispersed structure, whereas in the case corresponding to the normal system the eutectic is a coarse, coalesced structure. The mechanical properties obtained from both white and malleable (white heart) cast irons are superior in the super-cooled to those in the normal system.

33. It thus appears that, except in a few cases where a super-cooled gray iron is wanted for special purposes, gray-iron founders should aim at producing the normal system and white or chilled iron, and white-heart malleable founders, the super-cooled system. There appears no reason why this should not apply equally to black-heart malleable cast iron.

34. There is, consequently, definite scientific evidence to show that composition, even in a single size of bar, does not determine structure, so that analysis alone is not necessarily a reliable guide to mechanical properties. This confirms the principle previously adopted in Great Britain of avoiding incorporation in specifications of definite limits of analysis.

35. The mechanical results depend far more upon melting conditions. Small differences in composition, in fact, are now regarded as of minor importance. Furthermore, a particular composition may restrict a maker's use of raw materials and may stifle research directed toward getting better results from compositions outside the specification.

36. Hence, our principle is to leave the maker to obtain definitely specified mechanical test results. Incidentally, these results may explain the tenacity with which British founders adhere to fracture as a guide in buying pig irons, even when they have the analysis as well, for pig containing ferrite (fine graphite) will show dark areas where this structure occurs.

37. Chilled pig also may show this structure, particularly at the edges. Even when the structure is pearlitic, results on remelting are affected by graphite size in the pig, which is capable to some extent of assessment by fracture examination.

38. Thus we reach the criterion that is satisfactory to the engineer, namely, mechanical tests. As the user or buyer, his wishes carry great weight and are not likely to be overruled.

39. Hence, whatever use may be made of foundry or laboratory tests as auxiliaries, our main concern must be with mechanical tests. Proper correlation will do much to completely justify their use on fundamental grounds. Before considering them, it is necessary to consider more fully the influences affecting mechanical properties.

COMPOSITION AND RATE OF COOLING

40. It is generally accepted that composition and rate of cooling are determining influences on the mechanical properties

of cast iron, and that the existing methods of control, by which silicon content is suited to a particular dominating thickness, embody the principle involved. The changes brought about by variations in phosphorus are well known, although the role of manganese, in relation to sulphur, has been much debated.

41. It has recently been demonstrated[3] that manganese tends to graphitize gray iron up to a limit of about 0.3 per cent manganese in excess of the quota required to satisfy the sulphur as manganese sulphide (MnS); after that point, manganese tends to harden gray iron. The former action is indirect, due to the removal of the potent carbide-stabilizing action of sulphur, and the latter is the normal carbide-stabilizing action of manganese.

42. There is evidence that this is equally true of white-heart and black-heart malleable, although the curve of change connecting combined carbon content with manganese content is so flat that opinions may well differ as to the precise manganese value at which, other things being equal, the metal is at its softest.

43. Variations in rate of cooling are affected by considerations other than the mass and disposition of metal in the casting, its specific heat and thermal conductivity. The rate is affected by the pouring temperature, mold temperature and the mass, specific heat and thermal conductivity of the mold material.

44. In a given case, factors other than thickness usually can be kept reasonably constant. The influence of variations in rate of cooling, therefore, can be studied by testing bars melted under the same conditions and of the same composition, but cast in a range of sizes.

MELTING CONDITIONS

45. Variations in melting conditions influence the properties of the metal so markedly that they transcend such minor differences in composition as inevitably occur in ordinary practice, in spite of efforts to secure uniformity. These variations, not readily recognizable in practice—and as yet seldom recognized—are responsible for many anomalies met in foundry practice.

46. In a given foundry they may be due to atmospheric variations; changes in coke supplier or variations in supply; changes in raw material supply, such as pig iron and scrap; changes in melting practice, such as the use or disuse of ferroalloys; or variations in richness or leanness of ferroalloys (even

if amounts used are adjusted to get the same composition—for ferroalloys differ markedly in their carbon content and capacity for throwing carbon out of solution); variations in pouring temperature and general furnace practice, and so on.

47. Between foundries there may be differences due to methods of charging, furnace design, raw materials, fuel, fluxes, the method of make-up of charge, use of ladle additions, etc., even when they aim at the same ultimate composition and mechanical properties. Internationally, there are important differences in fuels and ferrous raw materials, the effects of which are not often appreciated.

48. The magnitude of the effects of these conditions and their wide variety are quite sufficient to justify the belief that every foundry, and even every casting, forms a case to be studied by itself. They give the metallurgy of cast iron and the practice of founding the charm of variety.

49. If the nucleus theory is correct, they operate by influencing the size and distribution of graphite; and in cases where the graphite size falls below a critical minimum by producing a complete change in structure.

50. As the effect of each variable becomes understood, foundries will more and more approximate the optimum condition of working and their test results will increasingly converge to the same point. Then, and only then, will the production of cast iron be completely controllable from the scientific point of view.

51. As an illustration of the effect of varying one of the normally operating group of melting conditions on irons of the same composition, two mixtures calculated to give the same composition in the casting were cast from the same cupola in bars 1.2 and 2.2 inches in diameter.

52. The first charge was made up of equal proportions of steel and white iron, with enough 12 per cent ferrosilicon and ferromanganese to yield a strong gray iron. The second charge was made up of the same materials, except that 40 per cent ferrosilicon was used instead of the 12 per cent—the proportion, of course, being lowered to give the same silicon content in the melt.

53. Unfortunately, the silicon contents differed somewhat in the two melts, but the illustration is strengthened thereby, because the higher-silicon iron is the stronger mechanically. The analyses are given in Table 1; mechanical properties, Table 3.

54. A simple change in raw material supply has produced, therefore, a change in test results that is consistent and by no means insignificant. Micro-examination revealed, in addition to the slightly larger amount of graphite in *B*, a coarser graphite structure, although both were pearlitic.

55. The influence of melting conditions, therefore, can be studied by testing bars of the same composition and of the same size, or range of sizes, melted with appropriate variations (preferably, of course, one at a time) in the conditions of melting.

56. Two conditions generally regarded as affecting composition are most conveniently treated as concerning melting conditions. One is the effect of graphite content. It is, in a measure, a function of melting conditions because, whatever the original total carbon content in an iron, the melting conditions will determine whether there is a carbon pick-up or a carbon loss, and how far this changes with remelting.

Table 3

MECHANICAL PROPERTIES

Diam. of bar, inches.	Transverse Test — Rupture, lbs. per sq. in. A	Rupture, lbs. per sq. in. B	Deflection, in. on 18 in. centers. A	Deflection, in. on 18 in. centers. B	Tensile test, lbs. per sq. in. A	Tensile test, lbs. per sq. in. B
1.2	72,500	70,000	0.24	0.24	45,000	40,300
2.2	64,250	59,800	0.19	0.22	35,800	33,400

57. MacKenzie has shown[4] that, irrespective of the total carbon content of the original charges, a given melting furnace tends to produce—and on sufficiently repeated melting will produce—a total carbon content peculiar to the furnace. Furthermore, the form (distribution) of the graphite has an important influence on the structure, and this (as shown above) is determined not by initial composition but by melting conditions—largely, the melting temperature and the time the metal is held at that temperature.

58. For the same reason, the use of steel or low-carbon scrap as a constituent of the melt (as an alternative to another mixture) must be regarded as altering the conditions of melting rather than composition.

59. In view of the attempts frequently made to associate the properties of cast iron with the sum of total carbon and silicon, or some fraction of the silicon content, it should be noted

that correlations are likely to be established only for one set of melting conditions (and, even then, unintentional changes may have occurred). Any attempt to do so for irons produced under various conditions usually fails, because it is impossible for any such formula to take into account the form as well as the quantity of graphite present.

60. The author has found such correlations when, and only when, melting conditions are maintained constant.[6] It seems probable that, when a set of melting conditions remains constant, the form of graphite distribution remains approximately the same.

61. Similarly, many attempts have been made to establish correlations between different types of mechanical tests, whether such tests measure the same basic property or not. Individual investigators have no difficulty in establishing pairs of correlations for irons made from the crucible or from the same cupola, but they do not hold universally for all conditions of melting, and there is no difficulty in showing this.[5]

62. Table 4 shows at once the number and the range of correlations established by individual investigators; and if the equations for any pair of tests are plotted, the variations are striking. Indeed, they indicate the range of variation to be expected from differing melting conditions.

63. Such correlations are only valid for one prescribed set of melting conditions. However, they may be established profitably by each foundry for its own purposes. Periodical checks then become an excellent test of progress and of any improvement in conditions of melting.

Test Procedure

64. At this stage we may formulate simple procedures underlying investigations on cast iron tests, as follows:

(1) The effect of variations in composition on the properties of cast iron may be studied by testing bars of the same size, cast under the same melting conditions, but with appropriate variations of composition.

(2) The effect of variations in rate of cooling on the properties of cast iron may be studied by testing bars of different sizes made under the same melting conditions.

(3) The effect of variations in melting conditions—individual or aggregate—on the properties of cast iron may be studied

by testing bars of the same size and composition under varying melting conditions.

MECHANICAL TESTS

65. The decided preference of the engineer or inspector for mechanical tests must not blind us to the fact that they are susceptible of very great improvement in themselves and of a marked degree of correlation among themselves. Too often, the preference of the engineer has been dictated by forms of test piece and testing procedures found suitable for steel and other ductile materials.

66. Bars specified by engineers frequently ignore the connection between properties and rate of cooling, as in calling for a large casting to be represented by a small bar, and vice versa. This arises mainly when castings are covered by a bar taken

Table 4

RELATIONS BETWEEN MECHANICAL TESTS

T = Tensile (tons per sq. in.)
R = Transverse (tons per sq. in.)
C = Compression (tons per sq. in.)
S = Shear (tons per sq. in.)
B = Brinell (3000/10/30)

Tensile and Shear.

$T = 0.92S - 1.2$	(Audo)
$T = 0.9S - 1$	(Le Thomas)
$T = 0.75S$	(Est Rly.)
$T = 0.63S$	(Planas)
$T = 0.54S$	(Herman)
$T = 0.59S$	(Si $>$ 1.6, Pisek)
$T = 0.92S - 6.8$	(Si $<$ 1.6, Pisek)
$T = 0.854S$	(Rudeloff)

Tensile and Brinell.

$T = 0.13B - 8.25$	(Portevin)
$T = 0.11B - 4.23$	(Schüz)
$T = 0.17B - 17$	(Rudeloff I)
$T = 0.2B - 20.5$	(Rudeloff II)
$T = 0.17B - 20.7$	(Pisek)
$T = 0.045B + 3.2$	(Herman)

Compression and Brinell.

$C = 0.38B - 34.3$	(Le Thomas)
$C = 0.32B - 3.2$	(Portevin)

Tensile and Transverse.

$T = 0.5R$	(Jungst)
$T = 0.5R$ to $0.55R$	(B. C. I. R. A.)
$T = 0.475R$	(Rudeloff)
$T = 0.43R$	(Pisek)
$T = 0.49R$	(Bach)

Compression and Tensile.

$C = 2.5T + 18$	(Portevin)
$C = 4T$	(B. C. I. R. A.)

Compression and Shear.

$C = 3S + 3$	(Le Thomas)
$C = 285S$	(Herman)

Shear and Brinell.

$S = 0.13B - 12$	(Le Thomas)
$S = 0.08B$	(Ferrer)
$S = 0.29B - 35.6$	(Pisek)
$S = 0.15B - 16$	(Audo)

from a specification not necessarily relating to the same general type and size.

67. Further complication is introduced at times by the use of a bar cast as an integral part of the casting ("cast on"), although there may be no relation between the thicknesses concerned, or no instruction as to the place of casting-on, the length of the connectors or the disposition of the bar in relation to the cooling mass of the casting.

68. Circumstances making it impossible for him to do both, the founder often is forced at present to decide whether to make a good test bar or a good casting—or an unsatisfactory compromise.

EFFECT OF REMOVAL OF SKIN

69. The skin effect is an important consideration in mechanical tests. In some tests, such as transverse, the bar can be tested as cast or it can be machined prior to testing. In a gray bar the metal is more open and weak at the center than immediately under the skin. The progressive removal of stock will result, therefore, in a progressive weakening of the bar.

70. This effect will be considered later, but it is common experience, which the author has repeatedly confirmed by direct experiment, that skin-machining yields a stronger bar—it may increase the transverse strength 10 per cent. Early American tests showed that the removal of 0.25 in. of stock diminished the strength; but if, say, 0.06 in. is removed on a small bar, or 0.1 in. on a large bar, the strength is markedly increased, as is the deflection.

71. This probably is due to the fact that the skin of a green-sand bar contains minute superficial fissures which may cause premature rupture under test, and possibly a release of skin stress, of which the fissures may be regarded as evidence.

72. Bars tested in transverse as cast are erratic in their results, while skin-machined bars are more uniform and regular. Thus, it is to the interest of the manufacturer to skin-machine transverse bars, although this procedure is less necessary for dry-sand or oil-sand than for green-sand bars.

EFFECT OF THICKNESS

73. For a given mixture and assuming a gray structure throughout, a thick bar will be weaker, per unit of area, than a thin bar. By casting a series of bars varying diameters from the

same ladle (i. e., same composition and melting conditions), the author has shown that the change in strength with size is continuous, whatever type of test be adopted.[6, 7, 8]

74. For some tests—tensile and transverse, for example—it is easy to test the bar at or near the cast size. The alteration in mass effect due to skin-machining can be disregarded, as the effect on the section is slight.

75. For other tests, however—shear, compression, impact, fatigue—it is impracticable to test many sizes, as this would involve a battery of machines or very large machines. Generally, the number of sizes that can be tested is limited to one, and this usually is small.

76. Comparisons often are made between one type of test on bars at or near the cast size, and another type of test on small diameters machined from them, as if it were taken for granted that the metal behaves in the small size exactly as it does in the large size.

77. The soundness of this assumption—for it is only an assumption—must be examined in any consideration of correlation of available tests. Illustrations of the effect of skin-machining and of thickness may be considered most conveniently as arising from the tests concerned.

TRANSVERSE STRENGTH

78. This test remains the simplest, cheapest and most generally used test for cast iron, and the breaking load and deflection figures are universally understood. Its usual mode of interpretation, however, often yields results which are contrary to the facts, and precludes comparison between transverse and other specific stresses, such as tensile and compression, and between transverse results on bars of other shapes and sizes of the same material.

79. The author recommends, as a method of expressing transverse results, the conversion of breaking load into a transverse-rupture stress per square inch of the cross-section at fracture. The transverse test as ordinarily conducted forms a case of a weightless, end-supported, centrally-loaded beam.

80. For supports L inches apart, a central load of W lbs. gives a bending moment at the center of $\frac{WL}{4}$. The resistance

offered by the beam depends on its size and shape, and may be expressed as fZ, where f is the specific resisting stress set up in the beam, and Z is a constant (the section modulus) for a given section, taking into account the size and shape of the section.

81. Within the elastic limit, $fz = \frac{WL}{4}$. When the elastic limit is passed, the formula ceases to be strictly true; but it is convenient to measure the stress f at fracture by means of the value $\frac{WL}{4Z}$.

82. For a standard bar $\frac{L}{4Z}$ is obviously constant, so that $f = KW$. A straight line conversion is therefore possible from from W to f, and can be used for bars accurately machined to a given size before testing.

83. In practice, however, most bars are tested as cast, and it is practically impossible to cast a bar accurately to specified size. Where differences between cast and specified sizes are not ignored, the practice has grown up of converting by proportion the result obtained on the cast size to that which would be obtained on the specified size.

84. The author has shown[6] that this procedure is fallacious, since it assumes that the transverse-rupture stress is the same for both sizes. This is not the case, for the larger of the two sizes will have the lower breaking stress; and the greater the difference, the more pronounced will be the error.

85. While the error is small in converting to a nominal specified size from a closely approximating cast size, the conversion from small to large bars, and vice versa, gives completely erroneous results.

86. By substituting appropriate values for Z in the formula, the transverse-rupture stress can be expressed in terms of bar dimensions.

87. For the round bar generally used in the United States and now adopted as the British Standard, $Z = 0.0982d^3$, where d is the bar diameter. Hence, $f = \frac{WL}{0.39d^3}$. For a bar tested at

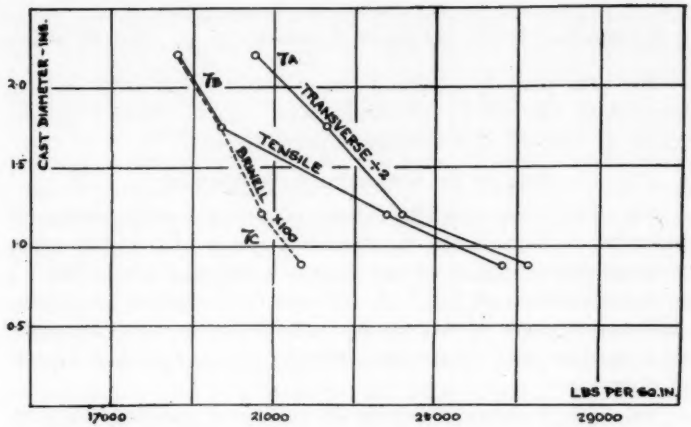

FIG. 7—VARIATION OF TRANSVERSE AND TENSILE STRENGTHS AND BRINELL HARDNESS WITH DIAMETER OF CAST BAR FOR SKIN-MACHINED BARS.

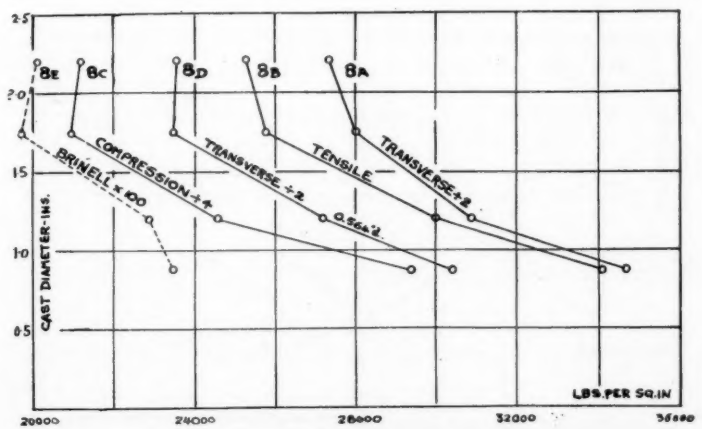

FIG. 8—VARIATION OF TRANSVERSE, TENSILE AND COMPRESSIVE STRENGTHS AND BRINELL HARDNESS WITH DIAMETER OF CAST BAR FOR SKIN-MACHINED BARS (*A*, *B*), AND BARS MACHINED TO 0.564 IN. DIAMETER (*C*, *D*).

18 in. centers, f in lbs. per sq. in. becomes $\frac{0.0205W}{d^3}$, for W in lbs.

88. The precise nature of change of strength with section, obscured by the use of breaking loads, can be readily demonstrated by the use of transverse-rupture stress.

CHANGE OF STRENGTH WITH SECTION

89. The nature of the change of strength with section is illustrated in Figs. 7 and 8, where curves 7*A* and 8*A* represent the transverse strengths of two irons of analyses given in Table 1 for bar diameters of 2.2, 1.75, 1.2 and 0.875 inches. Half the transverse strength in lbs. per sq. in. is plotted against diameter, and it is clear that transverse strength increases with diminishing diameter.

90. Fig. 9 shows a similar curve drawn smoothly through the points, for a series of eleven bars from the same ladle, varying in diameter from 0.5 to nearly 5 in. Curve 9*A* represents the curve obtained on the bars as cast, and curve 9*B* on similar bars skin-machined, which are higher by some 5 per cent. The amount removed in each case was about 0.05 in. The span in this series of tests was 21 in.

91. The slope of the curve is determined by many factors in the melting conditions apart from composition, and, while

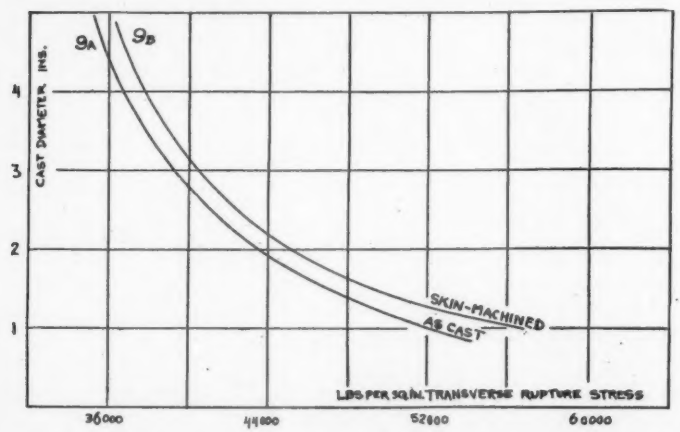

FIG. 9—VARIATION OF TRANSVERSE STRENGTH WITH DIAMETER FOR CAST AND SKIN-MACHINED BARS.

these curves are of similar type, the multitude of factors affecting the issue renders it unlikely that the change is represented by any simple physical law. There seems little point, therefore, in plotting the results on a logarithmic basis.[9]

92. A number of such curves have been so treated without yielding a simple physical law. In some irons the size-strength curve is almost straight and vertical, the heavy sections being nearly as strong specifically as the lighter sections, while in other cases the specific strength of thicker sections falls off sharply.

93. Size-strength curves may be prepared for a given set of melting conditions (i. e., in any one foundry) for various compositions, particularly silicon contents. As would be expected, the low silicon irons, being strongest, are on the extreme right of the chart, and intermediate and high-silicon irons are more or less parallel and farther to the left as the silicon increases.

94. Fig. 10 shows a chart for three mixtures of remelted pig iron from one foundry, analyses being given in Table 1.

95. It will be obvious that the establishment of a continuous variation of strength with section provides the basic justification for specifying a test bar for a given casting approximating the thickness of the casting.

96. It may be noted that the diameter d, chosen as an index to rate of cooling, is reciprocally proportional—if in a long bar

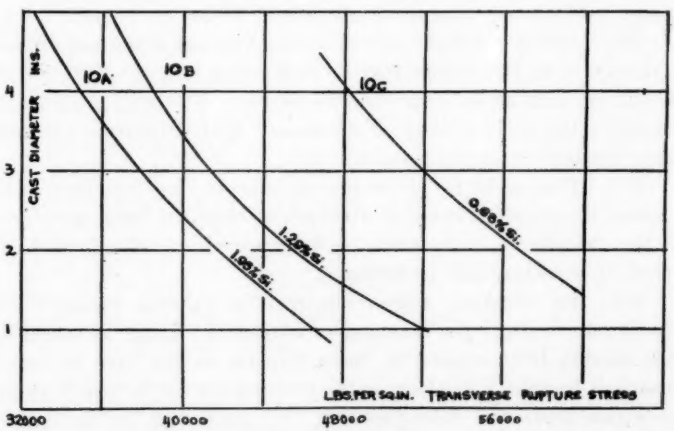

FIG. 10—VARIATION OF TRANSVERSE STRENGTH WITH CAST DIAMETER FOR MIXTURES OF REMELTED PIG IRONS.

the influence of the ends be ignored—to the ratio $\frac{\text{area}}{\text{volume}}$, recommended by J. W. Bolton,[10] which in a cylindrical bar is $\frac{4}{d}$. The author, however, has not found this ratio satisfactory for complicated shapes.

97. The change of strength with section for a given range of sections is a maximum for separately cast bars. In a casting of varying sections, the thin parts will gain heat from thicker parts and cool more slowly, and vice versa for thick parts.

98. Hence, while results on bars do not apply to the actual castings, they may be regarded as furnishing the extreme case. And, by experiment, a size of test bar may be chosen in excess of the dominating section of the casting which will give strengths similar to that of the casting.

99. The tests mentioned above have been carried out on a strictly standardized basis, for the transverse-rupture stress varies not only with size but also with shape. The British Cast Iron Research Association has shown, for instance, that a square bar is weaker, area for area, than a round bar; and that the result is not due to a casting effect but to a testing effect, for the difference between round and square bars (when tested as cast) persisted when round bars were tested after machining from the square, and square bars after machining from the round.[11]

100. The stress distribution during the test doubtless differs markedly from the theoretical in each case, and the differences are not parallel as between the two shapes. The author also has confirmed the observations of Mathews[12] that transverse-rupture stress diminishes as span increases.[13]

101. Hence, it is necessary to add to the previous conclusions the requirement that strength of cast-iron bars examined by the transverse test must be determined on standard bars tested by standardized procedures.

102. By treating transverse results on this basis, it is practicable to show the continuous nature of change of strength with section from results in many papers, as far back as those published in 1837.[14, 15] Particular interest also attaches to early American studies of this question, [16, 17] published by the American Society of Mechanical Engineers and the American Foundrymen's Association.

CHANGE OF STRENGTH WITH COMPOSITION

103. It is evident from Fig. 10 that strength changes with silicon content as well as with size. In Fig. 11 the transverse strength is plotted against silicon content for each of the three mixtures illustrated in Fig. 10.

104. As might be anticipated, there is an increase of strength as silicon content diminishes. Similar curves derived from results published by Rother and Mazurie[18] are practically parallel straight lines.[6]

105. Such a group of curves should be of great value to any foundry determining them for its own mixtures, as silicon is the usual basis of control. They enable the strength obtainable in a given size of bar to be predicted for a given silicon content, and vice versa. They should be of value to designers, and they permit the influence of changes in the melting program—such as the use of steel additions—to be readily determined.

106. It is suggested occasionally that it is useless labor to obtain a range of test bars in varying diameters and of one composition for the purpose of charting a size-strength curve, since commercially only one thickness or narrow range of thicknesses is suited to a particular silicon content.

107. There is considerable doubt, however, as to the precise limits of silicon content for a given thickness—even when con-

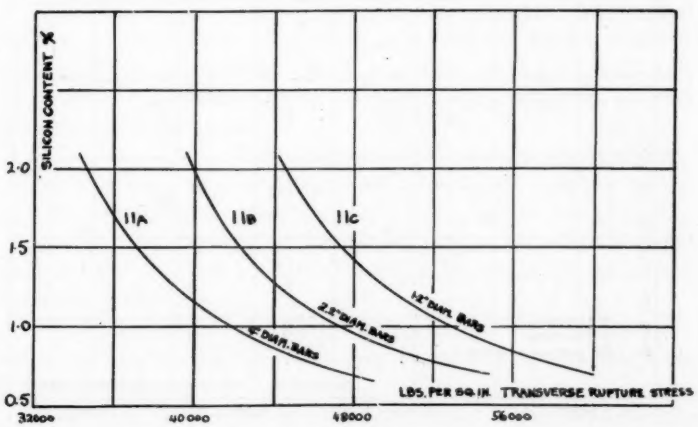

FIG. 11—VARIATION OF TRANSVERSE STRENGTH WITH SILICON CONTENT FOR BARS OF VARYING DIAMETERS.

fusion due to the effect of mass, variations in other constituents and in melting conditions is avoided—on account of the varying margins used in the industry against hard spots and mottling, or to the relative degree of inconvenience of these troubles.

108. The temptation to use one mixture for a variety of

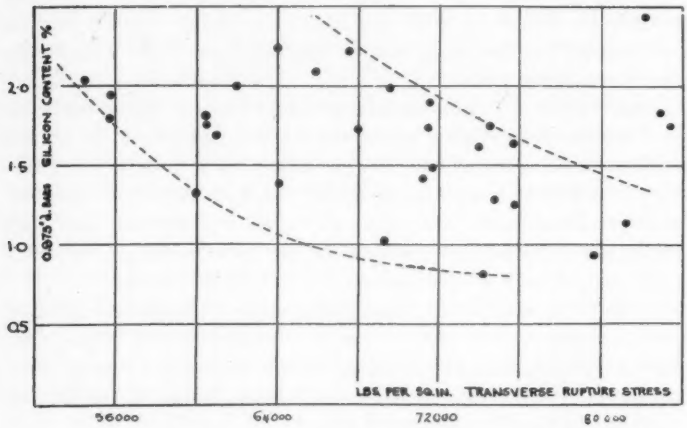

FIG. 12—TRANSVERSE STRENGTHS OF 0.875 IN. DIAMETER BARS OF VARYING SILICON CONTENTS FROM A NUMBER OF FOUNDRIES.

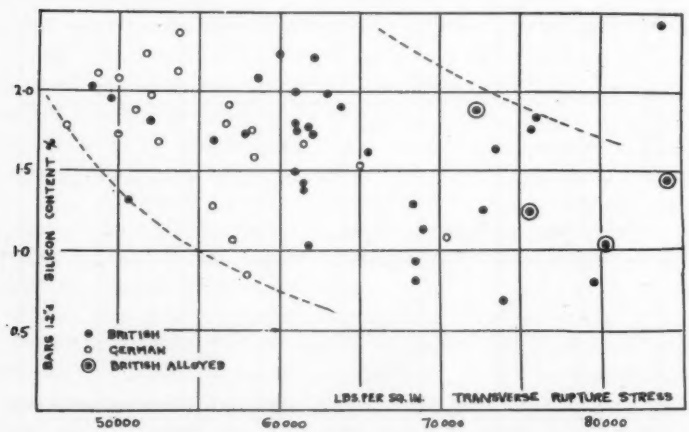

FIG. 13—TRANSVERSE STRENGTHS OF 1.2-IN. DIAMETER BARS OF VARYING SILICON CONTENTS FROM A NUMBER OF FOUNDRIES.

castings in jobbing practice also obscures the relationship. The establishment of size-strength and size-composition curves may be regarded, therefore, as the first step toward a knowledge of the precise composition required to produce a given strength.

109. The latter curves give the thickness at which the strength is a maximum for a given composition, and to this basis safety margins can be rationally added. Naturally, it is not necessary to have the full range of diameters for every silicon content.

110. When the iron changes from gray to mottled or white, the size-strength curves frequently bend sharply and strength begins to diminish as size diminishes. Thus, there are two diameters of the same strength, one harder and one softer than the maximum. White iron often proves stronger than gray, but its brittleness prevents an accurate idea of this being obtained. The strength of white iron is very erratic.

EFFECT OF VARYING MELTING CONDITIONS

111. The effect of variation in conditions of melting may be illustrated by the scatter in Figs. 12 and 13, in which a number of results are recorded.

112. A score of foundries, members of the British Cast Iron Research Association, were asked to cast bars from a cupola-melted mixture made in the ordinary way of business and suitable for engine practice—either ordinary cylinder or turbine quality, or the still better quality required for Diesel engines. Each mixture was represented by four bars—0.875, 1.2, 1.75 and 2.2 inches in diameter—three of these being standard British bars, as indicated below.

113. In Fig. 12 silicon content is plotted against transverse strength of 0.875 in. bars expressed as a specific stress in the way suggested above. In Fig. 13 the same figures are given for the 1.2 in. bar, represented by closed rings. The double rings show results on alloy cast irons containing nickel, tested under the same conditions.

114. Much work on alloy cast irons has been carried out recently in Great Britain, with very promising results, as these figures indicate.

115. The bars charted contained about 1 per cent nickel. The open rings refer to a series of melts recently made in Germany for the purpose of ascertaining how far a group of foun-

dries could meet a given specification (48,200 lbs. per sq. in. transverse) with their own charges and with specified charges.[19] The scatter is shown to be equally pronounced.

116. Dotted lines in Figs. 12 and 13 show the approximate limits of strength obtained from irons of the same silicon content; the range is nearly ±30 per cent on the mean for the 1.2 in. bars, and somewhat less for 0.875 in. bars. However, each set of bars in the British tests showed consistent results among themselves with regard to change of strength over the range of sections cast, as shown by Figs. 7 and 8, which represent two of these mixtures.

117. Furthermore, where more than one mixture came from the same foundry with the same melting conditions, the change of strength with silicon content was similar to that shown in Fig. 10.

118. Where the melting conditions had been altered, as by the use of a steel charge, this relationship did not hold. Fig. 16 will serve to illustrate this, for all four mixtures there represented were poured in one foundry and the strongest iron (*A*) had a silicon content almost as high as any other iron in the group. *B, C, D* followed in this order of increasing silicon, as would normally be expected from the strengths shown.

119. Analyses are given in Table 1.

120. In view of the tendency to the wider use of the tensile test, Fig. 14 gives the tensile strength taken on the 0.875 in. bar, plotted against silicon content, for the same British series as in Fig. 12, with a few other available figures. The definition of an iron mechanically by a combined transverse and tensile test suggests that it may be indicated conveniently in relation to other irons by using the two strengths as coordinates.

121. This is done in Fig. 15. As in Fig. 13, closed rings refer to British series, with a few other available results. Double rings are alloy irons; open rings, German irons.[19]

122. On this chart, specified transverse and tensile tests for a given iron can be defined by a point which is the origin of an upper right-hand quadrant. Any irons tested, falling in this quadrant, pass the specification.

123. Thus, closed squares marked *C* and *A* define the mechanical properties of the grades *C* and *A* of the British national specification 321/1928.[20] Similarly, open squares *P, Q, R, S* refer to four specifications recently adopted in Germany,[21]

while double squares W, X, Y, Z refer to the United States specifications[22] for ordinary grades and high-test iron.

124. It will be obvious that, in spite of a considerable measure of scatter, there is an approximate relation between transverse and tensile tests. That part of the curve drawn as a straight line broadly averaging the British and German figures, gives for tensile strength in lbs. per sq. in. (T), and transverse strength in lbs. per sq. in. (R), the equation $T = 0.59R - 4000$.

125. Any pair of values gives the approximate ratio R/T as 1.86. For a given tensile strength, the British specified transverse values lie between the German, which are the lowest, and the American, which are highest.

126. The ratio of R to T is not constant. It diminishes for high quality and increases for lower quality irons, as the range of tensile strengths is wider than the range of transverse strengths. This variation would be expected on theoretical grounds.

Deflection in Transverse

127. The deflection figure on transverse yields much important information, and the deflection figures for all the

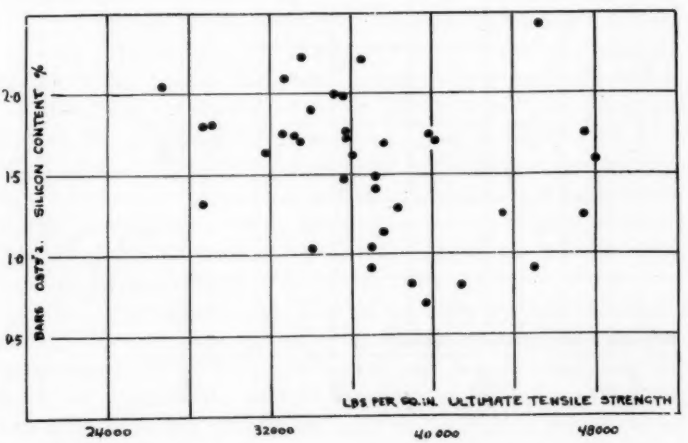

Fig. 14—Tensile Strengths of 0.875-In. Diameter Bars of Varying Silicon Contents from a Number of Foundries.

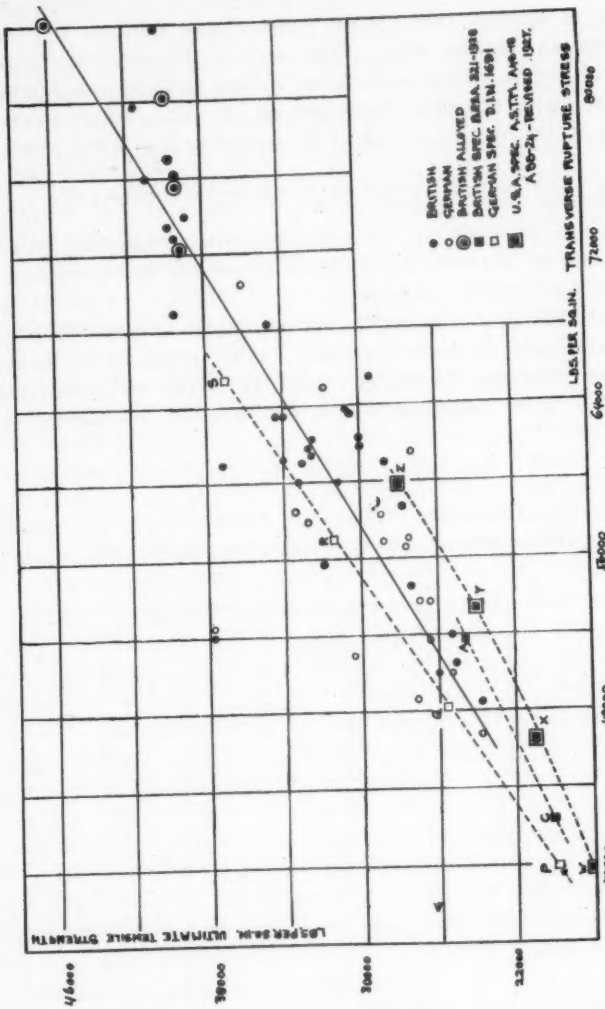

FIG. 15—TRANSVERSE AND TENSILE STRENGTHS OF 1.2-IN. DIAMETER BARS FROM A NUMBER OF FOUNDRIES, WITH RECENT SPECIFIED FIGURES.

transverse tests obtained in this paper have been obtained. In many bars the deflection has been taken at intervals in the loading in connection with the study of the elasticity of cast iron, since the breaking deflection is only partly elastic, the remainder being plastic—although the major part of the deflection, some 80 to 90 per cent, is elastic.

128. This question, however, is so comprehensive that it is thought best to reserve its treatment for a separate paper. Although engineering design is based on elastic phenomena, the engineer at present does not concern himself with elastic properties, so far as cast iron is concerned.

TENSILE STRENGTH

129. The engineer prefers the tensile test to any other, and with good reason. There is a vast body of accumulated experience existent in works on the technique of tensile-testing and it is our experience that for cast iron the tensile test, properly conducted, is sensitive, consistent and reliable.

130. Regular changes with composition for similar melting conditions and duplicate test results repeatedly confirm this. Care must be taken that the pull is axial and, in this connection, it is advantageous to have the test pieces—which require no parallel piece for gauge lengths—tapering to the center where the fracture takes place.

131. A parallel gauge length is neither necessary nor desirable. In this respect, the standard American test appears preferable to the British test, with its gauge length of two inches.

132. The tensile test behaves similarly to the transverse in that skin-machined bars have a higher strength than bars pulled as cast, although the essential difference in testing procedure makes a comparison difficult. When stock is removed beyond that amount which gives optimum strength, the tensile strength diminishes, as shown in Fig. 16, which is on a series of 1.2 in. bars cast in four mixtures.

133. The higher the quality of the iron, the less important becomes the amount machined off, as shown by *A* and *B*. Machining economy, however, suggests that the amount machined off should be a minimum, and in the case of 1.2 in. bar the test results given in Fig. 16 suggest that the reduction should be no more than the grip conditions demand.

134. Tensile tests show the same relation between strength

and size as transverse tests, and Figs. 7*B* and 8*B* show tensile results on the same irons as illustrated in 7*A* and 8*A*, respectively.

COMPRESSIVE STRENGTH

135. The compression strength of cast iron, seldom taken nowadays as a routine test, shows the same variation with cast diameter as tensile and transverse. The compression curve for iron 8*A* is shown as 8*C* at a fourth the tensile scale, on bars 0.564 in. diameter.

136. The half and fourth parts taken for transverse and compression do not imply that $\frac{R}{T} = 2$, and $\frac{C}{T} = 4$, are the best ratios for these tests. Some degree of separation between the curves is desirable to avoid confusion to the eye.

137. The appearance of the compression curve to the left of the tensile and transverse curves is commented on below.

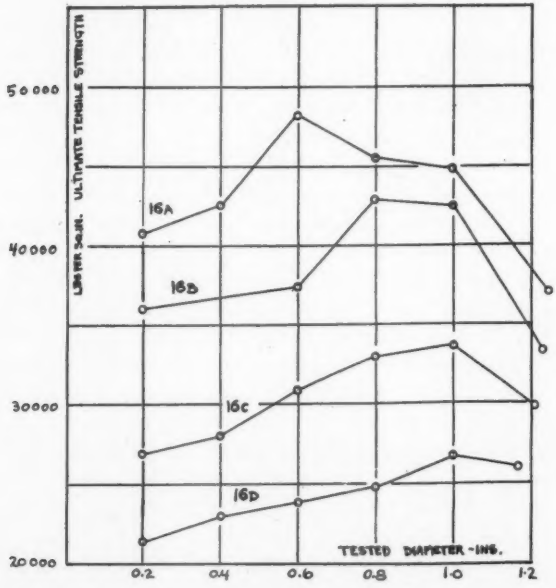

FIG. 16—TENSILE STRENGTHS OF FOUR FOUNDRY IRONS AT VARIOUS MACHINED DIAMETERS. 1.2-IN. CAST BARS.

RECENT SPECIFICATIONS

138. Since both transverse and tensile tests have been embodied in the specification issued by the British Engineering Standards Association (B.E.S.A.) in 1928,[20] a consideration of this specification is in place here.

139. The earliest cast-iron test bars used in Great Britain were one inch square (tested at 36 in. or 60 in. centers), but later the rectangular bar was adopted. The two bars hitherto used in the main have been the 1 in. square tested at 12 in. centers, and the 2 x 1 in. tested upright at 36 in. centers. Both have been embodied in earlier B.E.S.A. specifications for particular types of castings.

140. The new specification makes some radical departures in testing and, although the actual qualities of metal covered are only two in number, the testing provisions can be utilized for any size or type of casting. The main features are as follows:

(1) No chemical analysis is specified, the manufacturer being left to obtain the required mechanical properties by any mixture he chooses. This confirms the principle previously accepted in Great Britain that the quality of cast iron for engineering purposes can be defined by mechanical tests.

(2) The principle of a separately cast test bar is embodied in a British specification for the first time, although the purchaser still has the option of specifying cast-on bars if the design and method of running permit.

(3) Both transverse and tensile tests are specified, although the purchaser may be satisfied by either alone, if he so prefers.

(4) The cylindrical test bar is adopted for the first time in a British national specification, this rendering the square and rectangular bars obsolescent.

(5) The important principle is adopted for the first time of specifying a size of test bar comparable with size of the casting. Three sizes are provided, in fact, as a first step—the 1.2 in. bar, chosen because it has already received a measure of sanction as an international bar (New York, 1913), representing castings between ¾ in. and 2 in. main thickness; below 0.75 in. main thickness, the 0.875 in. bar, and above 2 in., the 2.2 in. bar.

141. The 0.875 in. transverse bar is cast 15 in. long and tested at 12 in. centers, and for tensile, reduced to 0.564 in. diameter. The 1.2 in. bar is cast 21 in. and tested at 18 in.

centers, and for tensile, reduced to 0.798 in. The 2.2 in. bar is cast 21 in. and tested at 18 in. centers, and for tensile, reduced to 1.785 in. The whole of the tests in the paper, unless otherwise specified, are carried out in accordance with this specification.

142. For other tests, in transverse testing a range of diameters, it was found desirable to standardize the span at 21 in., as in Figs. 9 and 10. The compression tests were carried out on cylinders 0.564 in. in diameter and 1.128 in. long.

143. British metallurgists have noted with interest recent changes in A.S.T.M. specifications and, in particular, the changes in the A.S.T.M. arbitration bar. In adopting the cylindrical bar the United States was ahead of Great Britain, but the single-size bar does little more than represent the metal in the casting.

144. To secure a closer relationship between bar and casting, instead of varying the thickness of the bar to suit the casting the principle has been adopted of varying the load and retaining the same size of bar.

145. It is feared that this procedure, ingenious as an attempt to retain the single-standard bar, does not wholly dispose of the difficulty, for many large castings would have a composition which would, in a 1.2 in. bar, run mottled or white. Several recent papers by authorities in America have expressed approval of the idea of relating the size of the bar to the thickness of the casting.

SMALL TEST BARS FROM HEAVY SECTIONS

146. We may now return to the question of heavy machining. We have seen that strength in the cast bar continuously increases as section diminishes. For some tests—compression, repeated impact and fatigue—it is imperative to machine a bar for testing, whatever its cast diameter, to a small diameter of the order of one-half inch.

147. What is the effect on the test results? A set of transverse bars similar in composition to the series illustrated in Fig. 9 was tested by machining to 0.8 in. diameter throughout, and these also were tested in tensile and compression at 0.564 in. diameter. The actual strengths obtained are plotted against the original cast diameter in Fig. 17*A*.

148. It will be seen that the increase in strength with diminishing section is equally marked. Taking into considera-

tion the change in the scale, it will be noted that a smooth curve through the points in *A* would be of the same character as, but to the left of, the similar curve on the cast or skin-machined diameters, shown in Fig. 9.

149. This weakness occurred in spite of the reduced span of 10 in. Thus, tests taken on small bars machined from larger diameters, will be relatively weaker than tests taken on the same bars at their cast or skin-machined diameters.

150. If a test taken on a series of diameters (skin-machined) be represented by a curve *A* in Fig. 18, and the same test be taken on the same series machined to the smallest diameter *d*, the change in strength series would be represented by a curve *B*, the difference depending on factors of composition and melting conditions. A curve *C* might represent all bars machined to a diameter *D* larger than *d*.

151. Therefore, while the assumption is erroneous as tacitly made in many papers—that tests may be made indiscriminately on any size of bar that suits the testing machine, irrespective of its relation to the cast diameter—the strength of a machined bar is determined by its strength in the cast state. Short por-

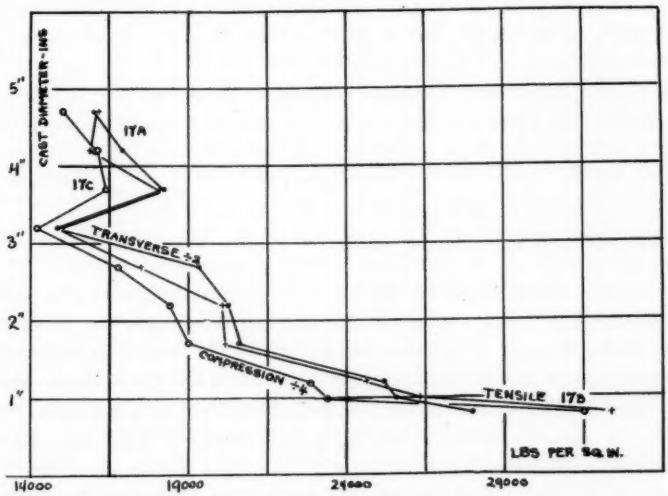

FIG. 17—TRANSVERSE TESTS ON SERIES SHOWN IN FIG. 9 AT 0.8-IN. DIAMETER AND TENSILE AND COMPRESSION AT 0.564-IN. DIAMETER PLOTTED AGAINST CAST DIAMETER.

tions of curves such as *A* and *B* at present may be regarded as parallel, without serious error.

152. In Fig. 8 the marked movement of the compression curve to the left is explained by the fact that each test was made on a 0.564 in. diameter bar. Had it been practicable to test each bar diameter in compression without more than skin-machining, it doubtless would have appeared adjacent to the tensile and transverse curves *A* and *B*.

153. The partial machining essential on tensile bars also explains that *B* is to the left of *A* in Figs. 7 and 8. Furthermore, in Fig. 8, *D* represents a series of transverse tests on bars represented in *A* machined to 0.564 in. diameter, tested at 7 in. centers. In spite of the shorter span, there is a distinct fall throughout in transverse strength.

154. Returning to Fig. 17, the transverse size-strength curve is not shown as a smooth curve because—for some reason at present obscure, but probably connected with an unintended change in melting conditions—the 3.7 in. diameter bar showed an increase in strength over the 3.2 in. bar.

155. It was thought that, if compression and tensile tests measured the same fundamental property as the transverse test, the compression and tensile values would show the same discontinuity. The tensile curve is shown at *B* and the compression curve at *C*.

156. As before, a tensile scale is adopted and the transverse results (*R*) plotted at one-half, and compression results (*C*) at one-fourth their true values. The mean value for R/T is, in fact, nearly 2, and for C/T nearly 3.75.

157. Thus, Fig. 17 shows that (when tested at the same diameter) tensile, compression and transverse results maintain a constant ratio to each other; and furthermore, that tensile, compression and transverse tests measure the same basic property of cast iron. Hence, we may look forward, as time goes on, to one of these tests being standardized and the others deduced from it.

158. If a set of bars of the same cast diameter be progressively reduced, all tests show a regular falling off in strength, as might be anticipated. A number of bars of the same metal and

of the same diameter, tested as cast in transverse, did not vary more than ±3 per cent from the mean.

REPEATED-IMPACT TEST

159. The development of high-quality irons has created a need for a test which will discriminate between ordinary and special irons with greater sensitiveness than ordinary static tests.

160. The transverse test, perhaps, is least satisfactory in this respect, and tensile is better. Shock tests appear to have possibilities, but single-blow tests—particularly those involving a notch—have not been found really satisfactory, while the time taken to conduct a fatigue test rules it out at present as a routine test, although some promising rapid methods are being developed.

161. A convenient test which falls intermediately between these two types of test is a repeated-impact test. In the form used by the British Cast Iron Research Association, the machine delivers about 80 blows per minute on to a standard Stanton test piece (a ⅝ in. round bar machined to 15 mm., with a round notch 3 mm. wide and 1 mm. deep), rotated through 180 degrees between the blows.

162. The number of blows to fracture is recorded. By suitable adjustment, several combinations of falling weight and drop can be used, and the B.C.I.R.A. standard has an energy impact of 0.48 ft. lbs. (4.8 lbs. falling through 1.2 in.).

163. The test is used on a purely empirical basis, and it is found that the impact value rises with diminishing silicon and phosphorus, diminishing graphite content and diminishing size of graphite.

164. An ordinary cylinder iron withstands 200 to 300 blows, while a special engineering iron may withstand 800 to 1000. In Europe the standard blow adopted is smaller, which gives, of course, a much greater number of blows before fracture.

165. The use of two standards creates some difficulty in transposing, but when it is considered that some experimental irons made by the B.C.I.R.A. have withstood nearly 100,000 blows, taking two to three working days to test, the inadvisability of a softer blow is obvious.

166. An approximate transposition might be effected by the use of a curve such as Fig. 19, which shows the results of a series of bars tested at each of the six combinations of weight and drop

available. It is not known whether curves for other irons would be similar.

BRINELL HARDNESS

167. Brinell hardness, if conducted with the 10-mm. ball, gives useful comparative data. The brinell hardness, however, does not appear to fall in the larger sections or rise in smaller

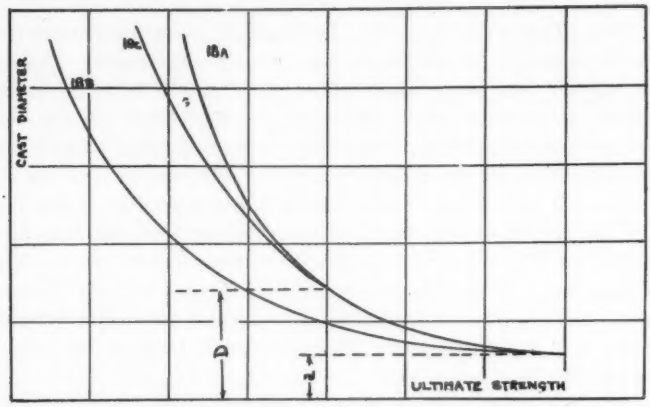

FIG. 18—SUGGESTED VARIATION OF STRENGTH WITH CAST DIAMETER AT VARIOUS TESTED DIAMETERS.

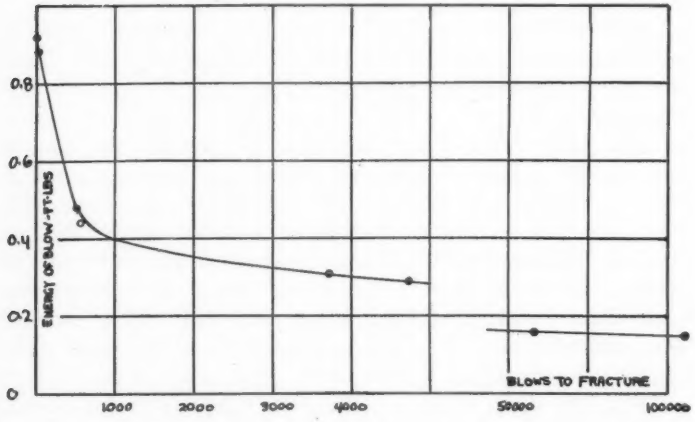

FIG. 19—REPEATED IMPACT TEST. RELATION BETWEEN ENERGY OF BLOW AND NUMBER OF BLOWS TO FRACTURE FOR THE SAME IRON.

sections as much as tensile or transverse strength. The slope of the brinell curve is greater.

168. The brinell hardnesses for the two irons shown in Figs. 7 and 8 are given at *7C* and *8E* for each diameter of bar, each point being the mean of three readings on the shank of the tensile bar. Obviously, therefore, the relation between brinell hardness and tensile or transverse strength, even for the same composition and conditions of melting, depends upon the size of standard test bar employed.

FATIGUE TESTS

169. Although comparatively little has been done in Great Britain on fatigue of cast iron, the results obtained at Illinois[23] and at Wisconsin[24] have been followed with interest.

170. Professor C. H. Bulleid of University College, Nottingham, has done a number of Wöhler fatigue tests on cast iron, and in conjunction with the B.C.I.R.A., a more systematic examination has been begun. In accordance with the systematic plan adopted for the static tests, it was desired to ascertain—for one set of melting conditions—the influence of composition (particularly silicon content) and the influence of rate of cooling, as governed by the thickness of bar tested.

171. For preliminary experiments, two mixtures, varying in silicon content, were cast in the same foundry, and the endurance limit was determined in the usual way, together with other tests. In another cast, the same melt was poured and tested in each of the two thicknesses.

172. The results show that endurance limit, like tensile and other static results, increases as silicon content diminishes; and that, like tensile and other static tests, it diminishes as the size of cast section involved increases. The endurance limit thus behaves exactly as do other tests, but further work is required before the existence of any direct ratio between endurance limit and other tests can be determined.

CONCLUSIONS

173. Several conclusions may be drawn from the foregoing data of this paper, as follow:

(1) The proper correlation of mechanical tests and comparison necessitates the use of standard bars of specified shape and size and standard test procedures, preferably on an inter-

national basis. The 1.2 in. diameter bar, representing a large proportion of castings made, and accepted in the leading industrial countries, is particularly suited for experimental work.

(2) Under constant melting conditions, gray irons of the same composition vary continuously in strength (transverse, tensile, fatigue, compression and hardness) with section, strength diminishing as the section increases.

(3) Under constant melting conditions, gray irons in the same size of bar vary continuously in strength (transverse, tensile, fatigue, compression and hardness) with composition (silicon content), strength increasing within the gray range as silicon diminishes.

(4) Differences in strength between gray irons of the same composition and same size of bar are an index to differences in melting conditions.

(5) Variation in strength of a series of bars cast at different diameters is shown equally well by tests at the cast size or at a constant machined diameter, but the latter are lower on account of stock removed. The extent of the difference depends on the nature of the iron tested. Skin-machining increases the strength of gray cast-iron bars.

(6) Transverse, tensile and compressive tests measure the same basic property of gray iron and, for standardized tests on the same size of bar, bear a constant ratio to each other for the same iron melted under the same conditions. Approximately, the transverse is double and compression four times the tensile strength.

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DISCUSSION

ORAL DISCUSSION

DR. R. MOLDENKE:* We in America have only one size of test bar. When word came over that England has three, to represent three of the many cross-sections of cast iron, I felt that their smallest size test bar would not interest us because we have had experience with Mr. Keep's ½-in. square bar, the results of which were not satisfactory. However, I am more favorably inclined toward their very large bar.

The point is well taken in England that they do not like to test an iron which will be just gray in fracture when in a large casting, but which will chill when put into a small bar. The quality of iron in the

*Watchung, N. J.

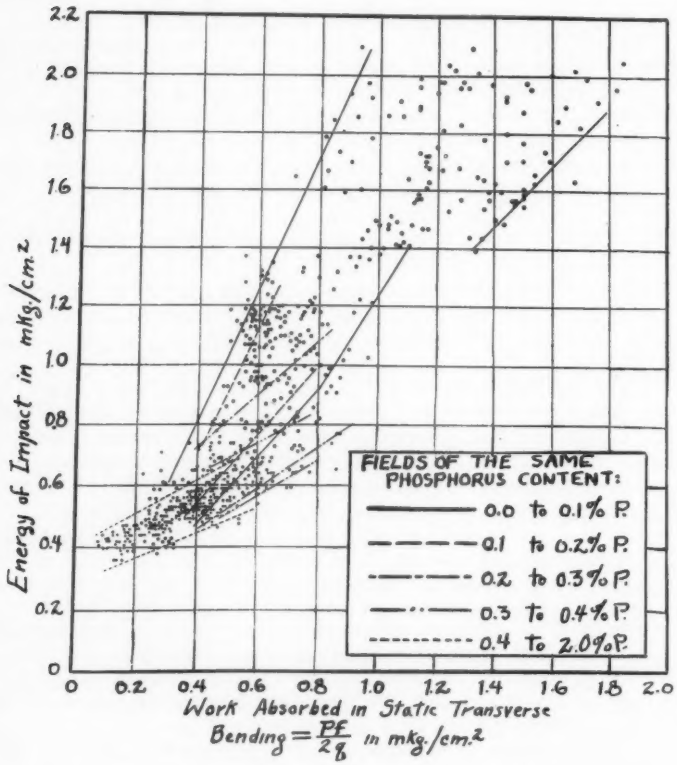
Energy of Impact in mkg./cm.²
Work Absorbed in Static Transverse Bending = Pf/2g in mkg./cm.²
FIELDS OF THE SAME PHOSPHORUS CONTENT:
0.0 to 0.1% P.
0.1 to 0.2% P.
0.2 to 0.3% P.
0.3 to 0.4% P.
0.4 to 2.0% P.
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

FIG. 20—RELATION BETWEEN IMPACT RESISTANCE AND TRANSVERSE RESILIENCE. SUMMARIZED FROM PAPERS BY WÜST; "FERRUM," 1913, 1914, 1915 AND 1916.

white bar cannot be compared with the quality of the iron in the gray-iron casting. The difficulty with the large bar, however, is that it requires a large testing machine, and we do not have such capacities over here in our foundry testing machines.

My reaction, therefore, is that we should not include their large bar as one of the standard bars, but should insert a clause in the specification calling for such a bar for the particular case where the iron will show mottled or white in the standard bar as ordinarily used.

The principle in paragraph 140 (5), of the author's paper, will show the difference between the American and the British thought as expressed by Mr. Pearce. In line 5, the author speaks of "representing castings between ¾ inch and 2 inches in thickness," etc. We should like to substitute the words, "representing the quality of the iron in the casting."

Another point which has not been touched on at all is that we aim to get the most perfect test bar we can make. Our castings do not get such preferred treatment, as they are subject to casting stresses, etc. Therefore, it cannot be said that a test bar represents the castings unless, possibly, the casting and test bar are given the same heat treatment. Then it may be all right to say that the test bar is a reasonable representation of the casting, for all practical purposes.

J. T. MACKENZIE:* The British attitude that the different size test bars will represent the casting, is finding increasing favor in this country. A few years ago anyone who tried to introduce any other test bars would have been shouted down, whereas now it is discussed seriously, and the committee is working on the bars with the idea of adoption.

Having recently broken some of these bars, I believe one thing should certainly be done in connection with the 2.2-in. bar. The span should be increased sufficiently to take care of the enlargement of diameter, so that we may get better deflection values.

I recently broke some bars of 2.2-in. diameter, using spans from four feet on down to 18 inches, and the deflection on a 2-foot span—which would not be out of the reach of most testing machines—was very good, ranging around one-fourth inch.

The British specification, with the intention of representing the casting by the test bar, yet states specifically that the test bar cannot be rumbled, even though the castings may be rumbled. I do not see just why that provision should have been put in.

Discussing the impact—on which the committee of the A. S. T. M. is now actively engaged—we do not consider the repeated impact test used by the British as good as the increasing height of fall of a standard weight—in other words, the regular impact test.

Part of the testing which Mr. Pearce has eliminated as being too long for discussion, was the modulus of elasticity, which I have used for some years as an index of the stiffness of the iron. This factor, which is nothing but the load divided by the deflection, is one of the most useful of the easily determinable properties of cast iron, and a great many of the properties of cast iron would run parallel with it.

*American Cast Iron Pipe Co., Birmingham.

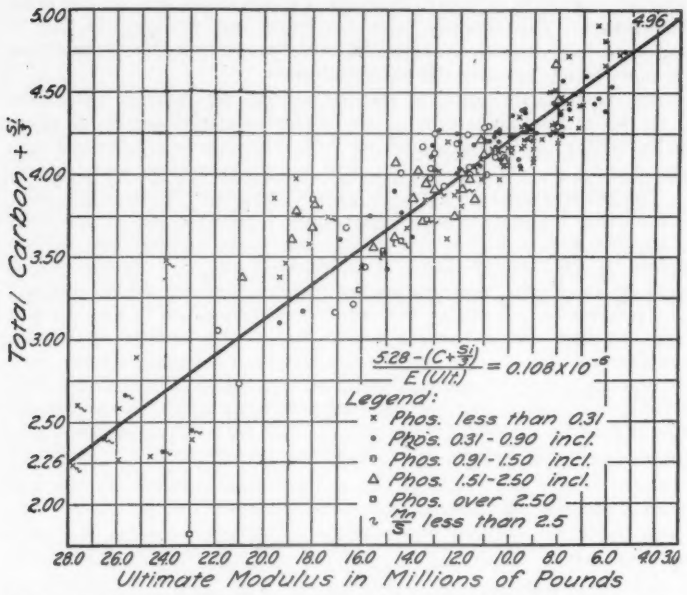

FIG. 21—SHOWING VARIATION IN STIFFNESS OF WHITE IRON WITH ANALYSIS, MODULUS OF ELASTICITY BEING PLOTTED IN DECREASING VALUES.

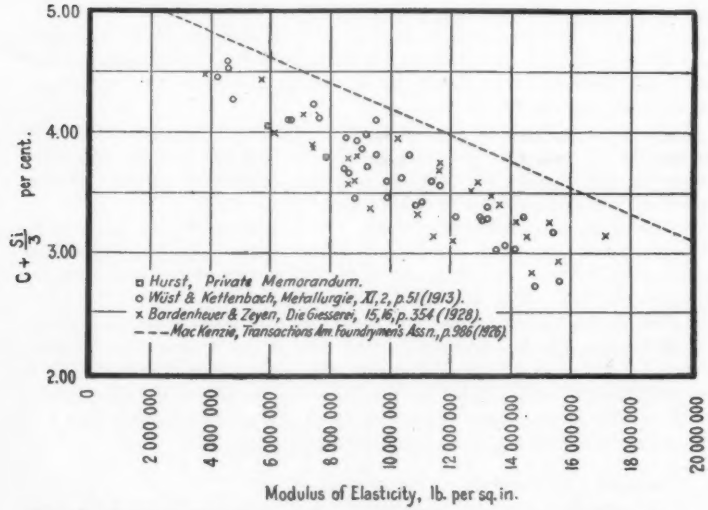

FIG. 22—SHOWING RELATION OF MODULUS OF ELASTICITY TO CARBON PLUS ONE-THIRD SILICON.

The chart of Fig. 20 is from a recent publication by Thum and Ude, and is a summary of the comparative results taken from the load multiplied by the deflection in the transverse strength (which is plotted horizontally) and the impact test (plotted vertically). These bars were taken from a very extensive series of investigations by Wüst some years ago.

As an indication of the variation in the stiffness with the analysis, the modulus of elasticity in decreasing amount is plotted in Fig. 21. The modulus of 28,000,000 lbs. is for a very stiff white iron, whereas that of 5,000,000 lbs. (which is the softest I have) is for a very soft, high-deflection iron. The vertical scale is the sum of the total carbon and one-third of the silicon.

The work which resulted in Fig. 21 was all done at Birmingham, Ala., but represents pig iron from India, Belgium, Great Britain, Germany, Wales, Pennsylvania and Alabama.

Fig. 22 shows a set of results taken from the same work shown in Fig 20. This is my own set-up. The dotted line represents the average from the previous figure, and the crosses and circles show the results from the German work indicated. As the phosphorus is very low in all these bars, it will be noted that the modulus is also lower than with my bars, which were about one per cent average phosphorus.

J. W. BOLTON:* In general, Mr. Pearce's paper agrees with the observations in the 1929 A. F. A. exchange paper to the I. B. F. However, due to the lack of close communication, Mr. Pearce has indicated in a few instances slight misconceptions on one or two points—misconceptions for which we may be initially responsible but which I trust Mr. Pearce's visit has now eliminated.

In paragraph 96 appears the statement: "It may be noted that the diameter *d*, chosen as an index to rate of cooling, is reciprocally proportional—if in a long bar the influence of the ends be ignored—to the ratio *area* ÷ *volume*, recommended by J. W. Bolton, which in a cylindrical bar is $4/d$. The author, however, has not found this ratio satisfactory for complicated shapes."

We should like to call attention to the work of the sub-committee of the A. S. T. M. entitled "The Correlation of Test Bar Data," presenting data showing the limitations of this test.

For all practical purposes where variations exist between the calculated and determined results—that is, calculating, from the size and strength of the bar, the strength to be expected in the casting—the calculated results (provided the feeding of the casting is correct) are lower than those actually found when testing the casting.

In other words, if one wishes to avoid using an expensive, long and absolute method (an absolute method gives an absolute result), and if one wants to use a short-cut or calculated method, this can be done without danger from an engineering point of view. The results of the calculation will be conservative as compared with those given by actual test.

I cannot forbear objecting to the use of the term "modulus of

*The Lunkenheimer Co., Cincinnati.

elasticity" in Mr. MacKenzie's discussion. The term means the relation between stress and strain within the proportional limit of the material. That applies only to the part of the curve, "Relation of Stress and Strain," that is a straight line.

In the case of cast iron, at least on initial stressing, we have a curve and we also have an almost infinite number of combinations of modulus of elasticity, if we so call them. The modulus varies for each and every given load.

I believe that it would be better to find some term more in line with the usual engineering practice to indicate what Mr. MacKenzie really means. The valuable point he has brought out is likely to lead to confusion because of the term "modulus of elasticity" employed.

R. S. MACPHERRAN:* We are all very much interested in this scholarly presentation by an international authority. I was especially interested in the English specification and to note, for example, that they do not include chemical specification with the physical. At times there has been a demand in this country for the introduction into our specification of some chemical analysis. To my mind, that would be a very great mistake.

I also note with pleasure that they highly approve of the tensile test, at the same time cautioning that the test be so made as to avoid any axial strain. We in America think very highly of the tensile test. In fact, I believe the tensile test is really safer to follow than is the transverse test.

The question was raised by several members as to why the British, instead of going to 2 inches, went to 2.2 inches. We are interested in hearing what Mr. Pearce has to reply to that.

Mr. Pearce speaks of the irons shown in Figs. 1 and 2 of his paper, and then, in discussing these irons, he speaks of the iron in Fig. 2 as shrinking normally, and of the iron in Fig. 1 as not shrinking. Once in a while we get an iron that does not shrink. It sets almost completely and then, all of a sudden, the iron will come back to the riser. I wonder if that is the case with this iron described by Mr. Pearce.

J. G. PEARCE: We have a good deal of sympathy with Dr. Moldenke's comments on the small bar, but I should like to suggest that there is a great difference in area between the Keep bar, which is ½ in. square with an area of ¼ sq. in., and the 0.875 in. bar, which has an area nearly two and one-half times as great.

Foundries which should cast the 0.875 bar, by reason of the sections involved, can and do cast it very successfully. Because of the improved technique in the foundries—better melting and better control—I believe we can make satisfactory small bars today better than we could, say, 10 or 15 years ago.

Listening to Dr. Moldenke's points about the large bar and the large testing machine, I feel—if he is prepared to admit the use of the large bar where the iron in a small bar might be mottled—that there is no difference between that and our own proposal. Our proposal is that the

*Allis-Chalmers Mfg. Co., Milwaukee.

large bar should be used where a small bar would be too hard to represent the casting.

We must face the fact that the foundries do not have very large testing machines. While that is an important consideration, it affects only the foundry making comparatively large castings, or the foundry to which the cost of a slightly larger machine ought not to be a ruinous matter. The 2.2-in. bar will require only a 5-ton machine even now, and if we were to adopt Mr. MacKenzie's suggestion of lengthening the span, it might be very much less.

With regard to the point about testing the iron in the casting or testing the casting, for myself I see no possibility whatever of a test bar (which is essentially a casting of uniform section) ever representing a casting which may vary in section. In the nature of things, this is not possible.

However, bearing that in mind, I believe there is a distinction between a bar cast in any size the engineer or buyer likes to specify—which measures the iron in the casting, so to speak—and a bar which may represent the casting because it has a section carefully related to the section of the casting itself.

If one desires the test bar to represent the casting—not merely in its structure but also in casting strains, porosity, segregation, etc.—then any relationship of that kind between test bar and casting is absolutely impossible, and the sooner we acknowledge it, the better. The only test which would accurately represent the casting, under such circumstances, is another similar casting.

We have approached the question from the other angle, saying, "Let us make a test bar that represents the casting in structure, then let us make the perfect casting, and we will get as complete a correspondence as is humanly possible between the test bar and the casting"—which we have hitherto failed to obtain.

The point raised by Mr. MacKenzie about the 2.2-in. bar is a good one. At one time we considered having all three bars made geometrically similar, and I believe that is the ideal arrangement. The main objection is that engineers might consider, in bars geometrically similar, that they ought to have similar strengths, whereas with cast irons the big bar, of course, will have a lower strength even when geometrically similar to the small one.

I do not see the force of this objection myself, because no engineer expects a large bar of cast iron to have the same specific tensile strength as a small bar. It was a point that was made and acknowledged by us, and our aim was to establish spans which would give a practicable deflection of not less than 1/10 inch. We think a deflection of 1/10 inch is quite easy and simple to measure, and quite sufficient as well. Furthermore, geometrical similarity makes the large bar awkwardly long.

I should add also that our specification provides that the test bar shall receive any heat treatment which is given the casting. The two are made absolutely similar in every possible way. If the casting is made in a green-sand mold, the test bar is made in a green-sand mold; if in dry sand, the bar is made in dry sand; if in chill, the bar in chill; if the casting is annealed, the test bar is annealed.

The question of rumbling, however, leads to the possibility of artificially modifying the test results, which is undesirable. Therefore, we thought it best to eliminate rumbling altogether. After all, one does not rumble the casting to improve it.

Regarding the impact test—which involves raising a weight to a successively increasing height and then letting it fall—this is a severe test and is quite well known in England. It is, of course, very empirical in character. The repeated impact test mentioned in this paper has not by any means been adopted universally in England. It is merely a means we use for distinguishing one high-quality iron from another.

I sympathize with what Mr. Bolton says about the measurement of elastic modulus based on the ultimate deflection at fracture. I feel that the modulus, taken in the form used by Mr. MacKenzie, is based on the elastic deflection, while in the case of the transverse bar supported at the ends and loaded in the middle, the deflection of fracture is composed of two components, (1) an elastic deflection and (2) a plastic deflection.

The ratio between them can be influenced by annealing and getting rid of possible stresses, by preliminary work and by under-stressing. My experiments show that the elastic deflection is about 60 to 80 per cent of the total, or even as much as 90 per cent. However, I find that it varies from iron to iron.

Thus, if Mr. MacKenzie wishes to work on elastic deflection, he ought to measure that particular elastic component or deflection and not the plastic component. I appreciate that this would be a difficult task, which is why I have not given more details regarding it in this paper.

All the measurements that Mr. MacKenzie quotes from Thum and Ude in the chart of Fig. 20 were made on elastic deflections, and not on total deflections as used by Mr. MacKenzie.

I hope Mr. MacKenzie will modify the name of his ratio in which total deflection is used instead of elastic deflection, just as I now advocate the term "transverse rupture stress" instead of "modulus of rupture" for cast iron. I have a tremendous admiration for the work he is doing and the time he is devoting to it, and my remarks are made solely in the interest of what I conceive to be scientific accuracy.

With regard to Mr. Bolton's point concerning the cooling ratio, after talking with him and examining the reservations he mentions in his later paper, I believe this may go far toward meeting the difficulties of the case. Mr. Bolton seems to establish his connection very satisfactorily.

I am glad that Mr. MacPherran made the point he did about chemical analysis, because we in England feel very strongly that the foundry must not be tied by chemical analysis. The issuing of chemical analyses by consulting engineers and purchasers generally is a nuisance and should be abolished. The sooner it is abolished, the better it will be for all of us.

Let the foundry be perfectly free. If we are going to measure the quality of cast iron by mechanical test, let the buyer's specification be on mechanical tests, and let him not tie our hands by chemical analyses. We can get these mechanical tests as progress is made or as research goes on, by differing chemical analyses.

We can get a given effect today with several different analyses, if

we want it. It is purely a question of manipulation in the shop, and we take a very strong stand against chemical specifications. Strength is governed by structure, and that is not entirely controlled by analysis.

Speaking of Figs. 1 and 2, Fig. 1 shows the iron which we find does not pipe. It actually shrinks in the riser, but the graphite expansion causes it to come back again. This is exactly as described by Mr. MacPherran. The ordinarily pearlitic iron will show a very distinct pipe in the usual way.

So far as the 2.2-in. bar is concerned, once the 1.2-in. size is fixed, I believe that Mr. MacPherran will agree that 2.2-in. is a convenient larger size, easily remembered.

J. T. MACKENZIE: Regarding this modulus of elasticity, it will be noted that in my paper I have suggested that a better term would be a "stiffness ratio," which undoubtedly it is. In the study of the so-called modulus of elasticity, recently there has come to hand a work by Thum in which he took steel bars and, by cutting them in various ways with a saw, with slits and grooves and notches, produced exactly the same curve—elastic or plastic, as one wishes to call it—as we find in gray iron.

There is no question but that the bending curve of gray iron is largely caused by the graphite. The modulus of elasticity of steel is affected very little by its composition. The hardest tool steel and the softest mild steel, within the elastic range, are both very close to 29,000,000 lbs. "ultimate modulus." When that is cut up with graphite, of course it is reduced.

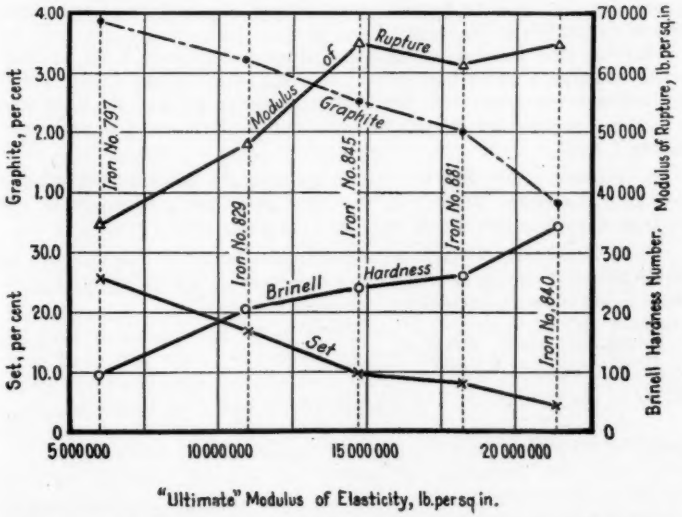

FIG. 23—VALUES FOR PLASTIC DEFORMATION (SET) IN SIX REPEATED LOADINGS TO THREE-FOURTHS ULTIMATE STRENGTH AGAINST ULTIMATE MODULUS OF ELASTICITY, WITH TREND OF STRENGTH, HARDNESS AND GRAPHITE INDICATED.

Referring to the chart of Fig. 23, this is from a paper presented before the 1929 meeting of the A. S. T. M. It will be noticed that the "ultimate modulus of elasticity" is the horizontal gradation. Against that is plotted the set or the plastic deformation in the curve at the bottom, and the graphite in the dotted line at the top.

It will be noted how remarkable is the correlation between the plastic deformation and the graphite content. That set amounts, on a very soft iron, to as much as 27 per cent, whereas on an iron that is beginning to be mottled it drops to 4 per cent.

CHAIRMAN H. BORNSTEIN:* Mr. Pearce has mentioned brinell hardness in his paper. That offers a fertile field for investigation, not only of the test bar but of the casting as well.

Recently we have had occasion to run a good many brinell tests on castings. We had a number of castings fail in service and we got them back, made tensile, transverse and hardness tests, examined the fracture and made chemical analyses. We found that the chemical analyses offered us no clue to the cause of failure, but we did find a very good correlation between the brinell hardness, transverse test, tensile test and the structure as shown by the fracture and examination under the microscope.

As a result, we put the brinell hardness test on production of this particular casting. We wanted the casting to stand a transverse load of 30,000 pounds per sq. in., actual load, and we ran brinell hardness tests for one month on each casting turned out. It represented several thousand tests, and we took several castings from each day's run, some toward the low side in brinell, some toward the high side and some toward the middle of the range.

We ran this test for one month and then continued it for another month, running a percentage inspection. We found a very good correlation between transverse test and brinell hardness, so that we were able to set up a specification of minimum brinell hardness on that particular casting.

A. SILBERT:† Mr. Pearce, you mentioned the introduction of fine steel into the ladle. Have you ever had good luck in machining the castings when you introduced steel into the ladle?

J. G. PEARCE: I should not recommend that as a practical job in the foundry for cupola metal. It is a device used in crucible melting in order to get very fine structure.

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*Deere & Company, Moline, Ill.

†Foote Bros. Gear & Machine Co., Chicago.

Report of A. F. A. Representative on Joint Committee on Investigation of the Effects of Phosphorus and Sulphur in Steel

To the Members of the American Foundrymen's Association:

Your representative regrets to report again, as he did at your 1929 convention, that no results of tests are yet in proper form for suitable presentation to indicate the influence of phosphorus on steel castings.

Brief consideration of the manner in which the work of the Joint Committee is conducted will serve to explain delays that would not occur in a purely commercial investigation undertaken in the ordinary manner by a private concern. As many of you doubtless remember, the Joint Committee was formed in 1919, under the initiative of the American Society for Testing Materials, the U. S. Bureau of Standards and the then existing U. S. Railroad Administration. The personnel now consists of representatives of the following 12 organizations:

American Foundrymen's Association.
American Petroleum Institute.
American Railway Association, Mechanical Division.
American Society for Testing Materials.
Association of American Steel Manufacturers.
National Research Council.
Society of Automotive Engineers.
Society of Naval Architects and Marine Engineers.
Steel Founders' Society of America.
U. S. Bureau of Standards.
U. S. Navy Department.
U. S. War Department.

Since the machining and actual testing of specimens has been chiefly conducted at the Watertown Arsenal and the U. S. Naval Experiment Station at Annapolis, supplemented by such assistance in the way of heat treatment and other details as is extended by the Bureau of Standards, the work of conducting the tests must necessarily be interrupted from time to time to prevent delay to work for the government, which is not being reimbursed for any of the expense of making the tests for the Joint Committee.

It is only fair, in this connection, to point out that the cooperation of the government—through the Bureau of Standards and the testing laboratories at Annapolis and Watertown—has represented an expenditure of many thousands of dollars and has been of tremendous value in this joint investigation. All steel foundrymen should be pleased at this

cooperative manifestation of the government in the solution of industrial and engineering problems.

As soon as conclusions can be drawn, substantiated by acceptable, detailed results of laboratory tests, the Joint Committee will authorize publicity as it has in the past—keeping in mind, in connection with the tests for determining the effects of phosphorus on cast steel, the right of the American Foundrymen's Association to be advised as promptly as possible regarding the tests on the material supplied by those who manufacture steel castings.

Respectfully submitted,

R. A. BULL

A. F. A. Representative on the Joint Committee on Investigation of the Effect of Phosphorus and Sulphur in Steel.

Progress of Die-Casting Industry

By Marc Stern,* Flint, Mich.

Abstract

Die casting is defined and its relation to a slush casting, permanent-mold casting, centrifugal casting and pressed casting is carefully pointed out, because of the tendency to confuse some of these terms. Early haphazard alloying methods which were responsible for unstable alloys are discussed, and contrasted with the progress made since the subject received scientific investigation. On the subject of dies, the importance of gating, venting and water cooling is pointed out. Air and plunger types of casting machines are illustrated, and progress traced up to the modern automatic casting machine capable of producing even complicated die castings at the rate of over seven operations per minute.

1. In order to clarify the subject under discussion, it would not be out of place to describe briefly the other methods of casting in metallic molds which are closely related to the die-casting process. Some confusion still exists as to the exact meaning of the term "die casting," especially in the minds of those who have access to British literature on the subject, where the term is used in an entirely different sense as compared with accepted use in this country.

Classification of Processes

2. The casting processes in metallic molds are subject to five variations, classified according to the method employed. These five processes are slush casting, permanent-mold casting, centrifugal casting, pressed casting and die casting.

Slush Casting

3. A slush casting is produced by pouring metal into a metallic mold which is almost immediately inverted to expell or "slush" out the excess molten metal. A hollow shell or casting remains which has been chilled by and conforms to the surface of the mold. The thickness of the shell depends upon the mold

*Manager, Die Cast Division, A. C. Spark Plug Co.

and metal temperature and the time consumed before the excess metal is expelled.

4. This method is used for toys and articles of a decorative nature, and complicated coring can thus be obtained in a very simple manner.

Permanent-Mold Casting

5. A permanent mold casting is produced by pouring metal into a metallic mold, and the gravity effect of the head of metal in the gate is the only pressure used. Thermal conditions of the various mold sections are vital to success, and risers or chills must be considered from the standpoint of progressive solidification toward the gate.

6. Cored sections are produced either with metallic or sand cores. This process has a broad field of engineering application. The term "gravity casting" would be more appropriate for the process, because the word "permanent" has no place in any casting process where the wear and tear of molds must of necessity be quite a factor.

Centrifugal Casting

7. A centrifugal casting is produced by pouring metal into a rapidly rotating mold, the centrifugal action forcing the metal to conform to its shape before solidification. It is applicable to practically all metals from babbitt to cast iron.

Pressed Casting

8. A pressed casting, also known as the Cothias process (after its inventor), is a casting in which a predetermined amount of metal is poured into the mold. A core or plunger is caused to descend rapidly into the mold, and the resulting force presses the metal into all sections of the cavity. It is applicable to simple parts of open design.

Die Casting

9. A die-casting is defined as one formed by forcing liquid metal into a die or mold and maintaining the pressure until solidification is completed. In England such a product is identified as a "pressure casting," and there the term "die casting" is a general term applied to all the above casting methods.

10. It will be noted that in the first four methods of casting the molten metal is initially introduced into the mold by

pouring, while in a die casting the metal is *forced* in from the start, under the influence of either mechanical or gaseous pressure. This accounts for the fact that the first four methods produce a more solid internal structure by allowing ample time for the air to escape.

11. However, the die casting process overcomes this disadvantage by producing castings of sharper outlines, thinner walls, denser surfaces and of much more intricate designs, where accuracy and finish are most essential.

12. With this outline of the exact meaning of the term "die-casting," as generally accepted in this country, this paper will confine itself to a brief review of the progress made in the alloys, dies and machines of this important branch of the casting industry.

ALLOYS

13. Tin and lead alloys were first utilized in the production of printing type and were later applied to the die casting of other parts because they could be handled most easily from a casting standpoint. In spite of the fact that rule-of-thumb alloying methods prevailed, they were not subject to serious consequences.

14. Their field of application outside of bearings, however, was limited indeed. The next step, therefore, was the production of zinc-base die castings because of the demand for something stronger and harder than lead or tin.

15. Thereupon casting troubles, however, multiplied. Pumping equipment deteriorated rapidly; thin sections would not fill up because of sluggish flow and, if they did fill up, a considerable percentage of die castings left the mold with visible or invisible cracks.

Cut and Try Methods

16. To overcome these troubles the production foreman would add a little aluminum or copper, or perhaps would drop a bar of tin into the casting pot. If the cracks stopped, that combination was maintained for that particular job. The next die casting may have had heavy sections, causing the excessive tin to "sweat" out—then another combination was attempted.

17. The supposition was that what produced the best casting was the best ultimate product, and little thought was given

to possible instability of alloys. It is no wonder that, with such haphazard alloying methods, untold injury was done to otherwise meritorious products utilizing zinc die castings.

18. Clearances in such devices were found to disappear after a short time, particularly in damp and hot climates. Parts subjected to even light strains suddenly broke after a few months' use, and others cracked while standing idle on the shelves. These were manifestations of the usual birth-pains associated with any new industry.

Growth of Metallurgical Control

19. From this chaotic state a better understanding of the properties of zinc alloys slowly developed. It was found that the combination of certain elements in zinc alloys, such as aluminum, in the presence of tin, lead or cadmium, produce very unstable alloys. They are subject to excessive internal oxidation or growth, and the deterioration is accelerated by vibration, heat and moisture.

20. The importance of careful metallurgical control was then realized, but it was not until about eight years ago that research worthy of the name was really started along this line. Zinc-alloy die castings are now commercially produced with a tensile strength of 30,000 to 50,000 pounds per square inch.

21. They are also sufficiently permanent for all practical purposes, as attested by the yearly production of hundreds of thousands of speedometers and similar devices in which clearances and spacings of moving parts are held to very close limits. Zinc alloys of even greater permanency in physical properties are now in the process of development.

Nonferrous Die Casting

22. When one considers the marked effects produced on the properties of alloy steels by the addition of minute quantities of various elements, it is to be expected that similar investigations in the nonferrous field will bring about equally beneficial results in this comparatively new industry.

23. Aluminum die casting was started commercially in 1914, and the selection of alloys from the standpoint of permanency was a comparatively simple problem, because of the experience derived from sand castings. The main difficulty was in the casting operation, due to the corrosive action of aluminum

on the pressure containers. The higher temperature and greater shrinkage caused abnormally high die maintenance. Die-opening mechanisms were also so slow that the castings would shrink on cores until they cracked.

24. These difficulties have been reduced greatly by the proper selection of alloys, improved casting equipment and the use of alloy steels for die construction. The steels generally used for this purpose are chrome-vanadium and chrome-tungsten —cobalt steels, but there is still much room for improvement, on account of the surface cracks developed which mar the appearance of aluminum die castings made from old dies.

Experience with Brass

25. The die casting of brass thus far has not proven a commercial success in this country, although it is being produced in limited quantities in Europe. The reason is that in a die casting one expects greater accuracy, and the casting of holes, threads, teeth, etc., so as to reduce subsequent machining to a minimum. However, such details are quickly destroyed by the greater shrinkage, higher temperature and rapid flow of molten brass, with the result that the high cost of die maintenance offsets the saving on the castings.

26. Success in this branch will come with the development of more durable steels. Permanent-mold castings in brass are commercially produced with apparent success, but they have a very limited field of application.

DIE CASTING DIES

27. The highest type of skill is needed in the workmanship of a die, especially when an intricate or accurate die casting is required. The impression must be polished free from tool marks or slight undercuts. But, however careful the workmanship, or however modern the casting machine may be, best results will not be secured unless the die is designed with the casting and the cleaning ends in view.

28. The parting, the gating, the venting, the location of the water-cooling channels and even the location of the ejector pins, have an important bearing on the result. It is difficult to reconcile, for example, the theoretical form of gate, which sometimes is subjected to considerable modification before a good die casting is produced.

Gating Uncertainties

29. One would expect that, in die casting a medium-sized flat plate free from holes or bosses, the gate should be led in gradually along the entire length of one edge and good results thus assured. Yet it is much more difficult to fill such a casting than if a number of holes or bosses were added.

30. Such surprises make it difficult to establish general rules in the design of dies. Experience is the only safe guide,

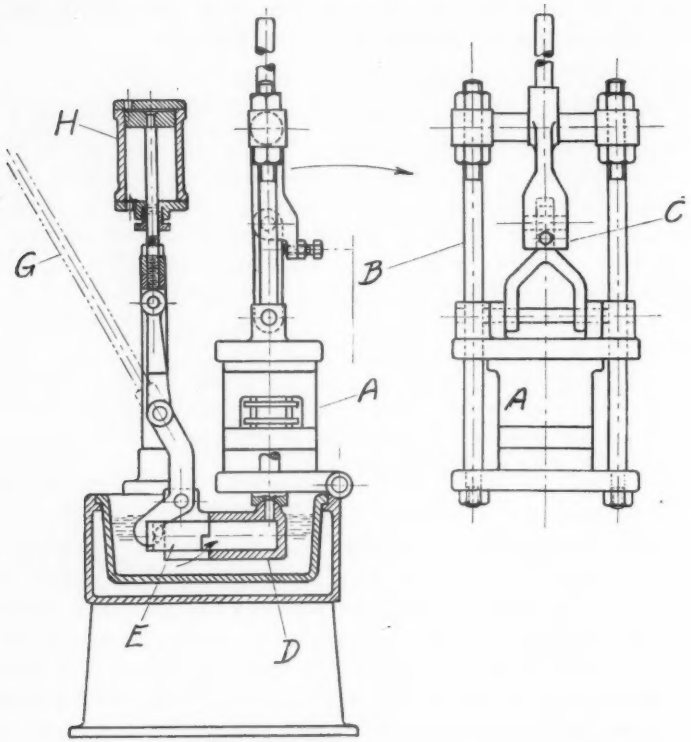

FIG. 1—AN EARLY MAKE OF DIE CASTING MACHINE, REQUIRING CONSIDERABLE MANUAL LABOR IN ITS OPERATION. THE DIE "A" IS LOCKED IN FRAME "B" BY MEANS OF TOGGLES "C." THE PRESSURE CHAMBER "D" IS SUBMERGED IN THE MOLTEN METAL, THE LONG LEVER "G" OPERATES THE PLUNGER "E" TO FORCE METAL INTO THE DIE. TO SWING THE FRAME INTO HORIZONTAL POSITION, IN ORDER TO REMOVE CASTING AND CLEAN NOZZLE NORMALLY, REQUIRES TWO MEN.

and it is the accumulated experience of the past years that makes possible the production of large and complicated die castings in aluminum, and in the lower-melting-point alloys.

DIE CASTING MACHINES

31. Great progress has also been made in the design of die-casting machines. Fig. 1 illustrates an early type of production machine, with the frame *B* containing the die *A* swung into the casting position. By the use of toggles *C* the frame locks the die securely. The whole frame is held against the nozzle of the pressure chamber by suitable locks, not shown on diagram.

32. The pressure chamber *D* is stationary and submerged in a pot containing the molten metal, and by pulling the long lever *G* (indicated by dot and dash lines), the plunger *E* forces the metal into the die. The frame is then swung to a horizontal position and opened to remove the casting.

33. Ordinarily, it takes two men to swing the frame and operate the various levers on the die. One man or, for larger work, two men were needed to pull the plunger lever.

Labor-Saving Equipment

34. Early in 1914, the first real effort was made to eliminate this strenuous manual work; the air cylinder indicated at *H* was adopted to replace the hand lever in forcing metal into the die. At first it met with serious opposition, because it was reasoned that it could not duplicate the "feel" of hand pulling, which formerly could be varied with different jobs.

35. However, this objection was due more to the mental inertia of old habits, and the change soon was generally adopted in the industry. Today the air cylinder is still in use on the plunger-type casting machine, together with the swinging-type frame, thus reducing the number of operators to two men, or, for simple dies, to one man.

36. As the dies increased in size, swinging the frame became a real hardship, and the horizontal type of frame came into use. The frame is operated by an air cylinder through a system of toggles, as illustrated in Fig. 2.

Power Elements Improved

37. The pressure chamber was also modified to the "goose-neck" type (*A* in Fig. 2), in which air is applied directly on the surface of the metal in place of the plunger, and this construc-

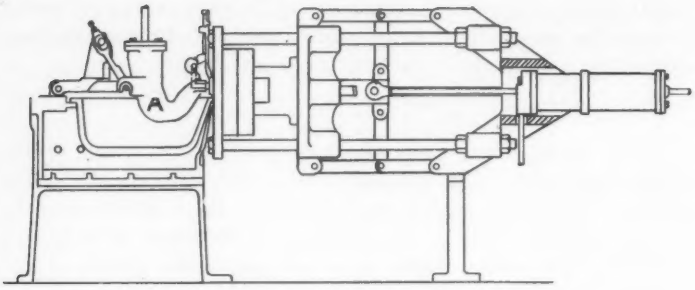

FIG. 2—DIE CASTING MACHINE WITH HORIZONTAL-TYPE FRAME OPERATED BY AIR CYLINDER THROUGH SYSTEM OF TOGGLES. THIS TYPE FRAME ELIMINATES LABORIOUS HAND SWINGING. PRESSURE CHAMBER "A" IS OF THE GOOSENECK TYPE, AIR BEING APPLIED DIRECTLY ON SURFACE OF METAL.

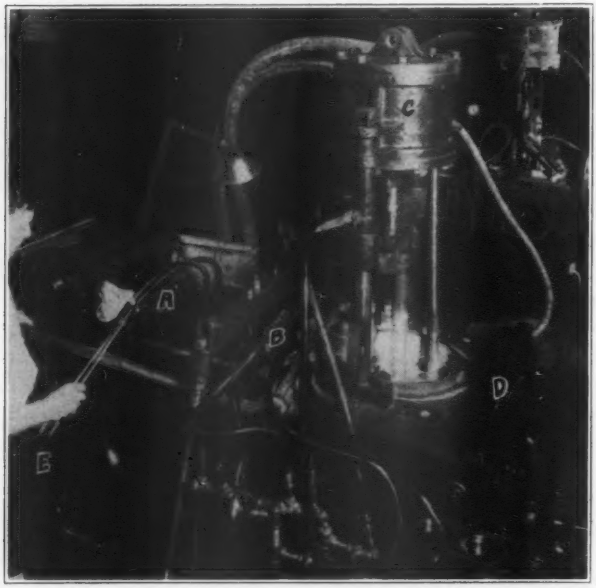

FIG. 3—DIE CASTING MACHINE OF RECENT DEVELOPMENT, WITH STATIONARY EJECTOR DIE "A" AND MOVABLE COVER DIE "B," WHICH IS THE REVERSE OF USUAL PRACTICE. PLUNGER OPERATED BY AIR CYLINDER "C" FORCES METAL THROUGH CENTER OF COVER DIE. FURNACE IS MOVABLE, BEING SUPPORTED BY SADDLE "D," THUS FACILITATING REPLACEMENT IN CASE OF BREAKDOWN IN FURNACE LINING.

tion is best suited for aluminum die castings. This type of frame, with minor modifications and in conjunction with either a "gooseneck" or a plunger style of pressure chamber, is also widely used in the industry today.

38. It will be noted that the source of power for operating the frame is air, which is not economical, of course. However, air was used for cleaning the dies anyway, so it was considered the quickest and most convenient form of power available. Furthermore, this development took place during the World war, when the demand for die castings was great and the labor supply limited, hence equipment was rapidly expanded on that basis without further experimentation. Later, hydraulic cylinders were utilized in some installations to open and close the die frame.

39. The industrial inactivity shortly after the war directed attention to further study of economical production. It was reasoned that, it being possible to apply power to the plunger and the frame independently, it surely ought to be possible to apply power to pull cores and eject the castings from the die. The result has been that we now have motor-driven, automatic die-casting machines that produce die castings in one continuous cycle, or series of cycles.

Modern Die-Casting Machine

40. Fig. 3 illustrates a recent invention based on a principle different from those previously described. The heavy portion of the die, known as the ejector die (shown at *A*), is stationary, and the cover die *B*, which is considerably lighter, is movable.

41. This is the reverse of usual practice, and provides better alignment of dies and more substantial rigidity in operating the core and ejector mechanism which are in the stationary die.

42. The air cylinder *C* operates the plunger, thus forcing the metal through the center of the cover die. This unit and furnace are supported by the saddle *D* which moves away from the cover die as it is being opened.

Advantages of New Equipment

43. This protects the die from absorbing an excessive amount of heat by radiation from the furnace. Another advantage of the movable furnace is the fact that it can be replaced

very quickly by another unit kept for emergencies in case of breakdown of the furnace lining.

44. The mechanism for pulling cores in the cover die is clearly indicated and is easily adjusted and operated, as are cores in the ejector die, which do not happen to be used on this particular die. All of the operations—such as the opening and closing of the die and nozzle, withdrawing or inserting cores in either die, applying and relieving the pressure on the metal and ejecting the finished die castings—are controlled automatically throughout a complete cycle, with the operation of a single lever *E*.

45. With such automatic casting equipment it is possible to double and treble production over that of the hand-operated casting machine, and it is not unusual to produce complicated die castings at the rate of over seven operations per minute. Such production widens the field for die castings because it now is possible to produce parts which formerly could be produced more cheaply by other methods.

46. The most desirable development, however, is the transformation of the casting equipment from a hit-or-miss proposition to one in which the personal equation of the operator is reduced to a minimum.

PRESENT TENDENCY

47. Concerns which, in the past, have established die-casting departments in their own plants, usually met with failure because of the necessity for highly specialized casting operators, and also because of frequent and costly replacements on the casting equipment. Early equipment was made entirely too light and too crude in construction to stand up.

48. It was not realized that pressure strains in the die often exceed 1000 lbs. per square inch, and parts were proportioned barely strong enough to hold this pressure. However, mass also is needed for rigidity if accurate die castings are desired, for the same reason that machine tools are constructed along massive lines for precision work.

49. It also is a notorious fact that many concerns whose names stand out in the public mind as symbols of progressiveness and efficiency, usually have a small department with antiquated die-casting equipment. The same management that would not

hesitate to scrap a battery of good screw machines for new equipment, which would reduce the operation time by a second or so, will still cling to die-casting equipment which was considered obsolete years ago. No doubt this is due to lack of familiarity with the process and its possibilities, and because of the rapid development of the industry in its methods and equipment.

DISCUSSION

ORAL DISCUSSION

S. TOUR:* In connection with zinc-base die castings it has been found that the main thing in zinc-base die casting is to avoid contamination of the alloy and to make the alloy itself out of high-grade, high-purity materials.

With this care being used in the making of the zinc-base alloy, using 99.99 per cent pure zinc, it has been possible to get zinc-base die castings of high strength, considerable ductility and great permanency. Test bars show nearly 50,000 lbs per sq. in. with an elongation of four to six per cent in two inches and practical stability as regards growth or deterioration in steam.

MEMBER: Mr. Stern, which do you consider the better type of machine, the gooseneck or the plunger type?

MARC STERN: I am very partial to the plunger-type machine, for several reasons. First, it is more economical to operate a plunger machine with a line pressure of perhaps 30 to 50 lbs., the multiplying action being done in an air cylinder. Therefore, it is much more economical than using direct air pressure of 300 or 400 lbs. per sq. in. Furthermore, the oxidation that takes place in a gooseneck is not very desirable.

The factor of safety in the gooseneck machine also is rather poor. If anything goes wrong in the plunger type, the only thing that can spurt out is the metal within the pressure chamber, which is comparatively small in amount. In the gooseneck, the entire pot will blow out until the valve is shut off. Of course, the air-chamber type of frame must be used for aluminum, but for zinc metal or a tin- or lead-base alloy, by all means use the plunger machine.

MEMBER: In regard to some of the alloys used in the aluminum die-casting industry, is it at all practical to use the same alloys without any changes that are used for sand castings—such as, for instance, No. 12, or S. A. E. 33—or must there be a change made in order to make the metal longer setting than would be required for sand casting?

MARC STERN: There is no change required for the usual alloys

*Lucius Pitkin, Inc., New York.

used in this country. No. 12 aluminum is cast successfully and some of the more popular silicon alloys are used. Thirteen per cent of silicon and the balance of aluminum is being used in sand-casting practice, and so it is in die-casting practice.

The advantage we gain in the die-casting equipment lies in the fact that everything operates rather rapidly and the casting can be ejected sufficiently fast to prevent the cracking tendency which might take place in a sand casting because of its slower removel.

MR. TOUR: With further regard to this question, there are certain sand-cast aluminum alloys containing zinc that do not function satisfactorily in the die-casting process. Sand-cast alloys such as S. A. E. 33 containing 2.5 per cent zinc, and S. A. E. 31 containing 12.5 per cent zinc, are too hot short.

MEMBER: Mr. Stern, have you ever noticed any corrosive action on the dies with the high-silicon aluminum alloys?

MARC STERN: All aluminum alloys show corrosive action on dies. I don't know whether we can claim that a high-silicon alloy will corrode a die any more rapidly than will, say, a No. 12 aluminum. A silicon alloy is, in the first place, handled at a lower temperature, perhaps 150 degrees lower, and the action is rather instantaneous on the die. It may have a tendency to solder a little bit, but it is not bad if the metal is not overheated.

MEMBER: Is it true that you are likely to get more blowholes in die castings made of, say, S. A. E. 33, than you would out of an alloy just as high in copper but with considerably more silicon?

MARC STERN: I believe that is more of an operating condition. I do not believe that the alloy itself would have any particular bearing on whether you get more porosity or not. The casting conditions vary with the different alloys, which have a vital bearing on solidity. If the metal is overheated too much, you will be likely to get more porosity.

MEMBER: Assuming that they were both carefully heated—what then?

MARC STERN: Personally, I can see no difference in the solidity if the casting conditions are right.

MEMBER: You mention here the instability of alloys—that is, when haphazard methods are used in their production. How about the stability of zinc-base die castings?

MARC STERN: They are highly satisfactory. Recent developments in the industry have brought about a higher grade of purity in the zinc and a greater knowledge on the part of all concerned regarding the importance of purity.

A small percentage of tin—no matter how slight it is, less than one-tenth of one per cent—or cadmium in minute quantities, will have an important bearing on the stability of the alloy. However, in those alloys that have a small percentage of unavoidable impurities, this action is compensated somewhat—in fact, it is fully compensated by the

action of a small percentage of magnesium, about one-tenth of one per cent.

Thus, you might say that the zinc-base alloys today are practically as permanent as pure zinc. That is attested by the fact that many speedometers and instruments having a high degree of accuracy are made in zinc die castings and there is no distortion that will affect their usefulness, even in damp climates.

H. M. ST. JOHN:* Is it not true that even with these modern zinc-base alloys, a certain amount of growth takes place in the casting for a time after it is made? And, if that is true, what is the smallest growth that can be expected? I am thinking now of a case where a casting contains a hole—a cast hole, we will say—that has to be machined out, around ¾ inch or one inch in diameter, on which the tolerances are quite close. What will happen to that in time?

MARC STERN: In speaking of permanency, the same thing is true of any metal. It is a pretty hard proposition even to machine a piece of cast iron and get a true hole and expect it to stay there unless extra precautions are taken. I have no data on the exact amount of variation on a hole of that size, but I do not expect that it would be any worse than, say, in iron casting. In fact, there are many accurate instruments today that are based on zinc die castings and no noticeable effect has been seen on them.

R. M. CURTS:† We have been engaged in research work on zinc-base die-casting alloys for the past eight or nine years. Obviously, one of our primary problems was to find an alloy which would be quite free from dimensional change during normal ageing. This research work has resulted in an alloy which meets the present-day commercial requirements quite satisfactorily.

The alloy I speak of is one containing 4 per cent aluminum, 3 per cent copper, 0.1 per cent magnesium and the balance high-grade zinc.

Comparative ageing tests show that after three years this alloy underwent a dimensional change of —0.0003 inches per inch, while its predecessor—the 4 per cent aluminum, 3 per cent copper, 97 per cent high-grade zinc alloy—revealed a dimensional change of +0.0052 inches per inch in the same length of time and under the same conditions. The latter alloy is still being used today, but it is being replaced rapidly by the alloy containing 0.1 per cent magnesium.

Some eight or nine years ago, a manufacturer employed zinc-base die castings in the construction of a well-known mechanical device. Some of these machines were subjected to warm, moist, tropical atmospheres, and in a comparatively short time the die castings had undergone enough growth so as to interfere with the proper functioning of the mechanisms. This experience caused considerable expense and inconvenience, but it resulted in a very painstaking investigation as to the cause of this unexpected dimensional change, following which a very satisfactory zinc-base die-casting alloy was discovered.

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*Detroit Lubricator Co., Detroit.

†New Jersey Zinc Sales Co.

The composition of this latter alloy has already been mentioned, and I have given you some idea of its improvement over the straight four per cent aluminum, 3 per cent copper alloy, which also contains high-grade zinc. The great improvement in zinc-base alloys is best evidenced by an ever-increasing employment of zinc-base die castings in many fields of modern industry.

MEMBER: With further reference to various alloys used in die castings, I should like to ask another question pertaining to that. Which alloys—or, I should say, which ingots—work better, in general, on the various alloys—virgin ingots or remelt ingots? While I would like to have the answer on a variety of alloys, I am referring particularly to S.A.E. 33, which is about eight per cent copper and a limit of 2.5 per cent zinc and iron and silicon and impurities.

MARC STERN: On some jobs, especially those with thin walls, secondary metals excessive in iron are rather difficult to handle because they are more sluggish in flow. However, on certain other jobs that have heavy walls, a better casting can be produced by using a certain amount of remelts. I would say that remelted aluminum, with the iron content and zinc held down to reasonable limits, is applicable to most jobs in a die-casting plant.

Nonferrous Cost Session

ORAL DISCUSSION

CHAIRMAN J. L. WICK:* It is apparent that figuring and knowing one's costs has not yet become the accepted thing in the nonferrous casting industry. It was mentioned by Mr. Runge during the discussion on gray iron costs than 85 per cent of the foundrymen in this country do not know their costs.

We have, of course, all been approached by the life insurance man. He says that of 100 men who start life at, say, the age of 21, by the time they are 62 perhaps there is one who has made an outstanding, financial success; two or three are comfortably well off; five or six are independent; 62 are dependent, and 30 have passed on.

An analysis of the Bureau of Internal Revenue reports, of the income tax returns, shows practically the same thing in regard to business firms. That seems to me logical, because the businesses that we represent simply reflect you and me.

In Barron's Weekly we are told that the number of failures in May, 1930, was 1,976; the previous month, 2,093, and for the same month last year, 1,735. Why have these firms failed?

The credit departments say: Character, or capital, or collateral, or capacity. I do not like to think that 85 per cent of our industry is made up of men who do not have the capacity to handle their problems.

Sometimes I get a real slant on my competition by putting in with my inquiries to the mercantile agencies requests for reports on my competitors. It was most gratifying last year to find these special notices come back on two direct competitors of mine, who came into my vicinity and took business right from under my nose, making me "look like a monkey" so that my customers would say to me: "Your costs are outlandish. Your prices are away off."

One of these concerns, I am advised, has been inactive since January 24 of this year. The company owes $130,000. They would like to make a settlement of 50 cents on the dollar.

I like to pay my bills. I like to have some standing with my creditors. That is pretty hard competition, and $130,000 is a rather high price to pay for a cost system.

In another case, a real estate mortgage for $30,000 was given to a man who happens to be a metal dealer. If that metal dealer were in the real estate business, I should think he would have gone out and advertised it. The giver of the mortgage is a man who comes right in and takes business from me every day. His cost system represents an investment of $30,000.

We have many reasons for getting together on some uniform basis of comparison. The splendid paper which Mr. Carter presented before

*Falcon Bronze Co., Youngstown, Ohio.

the gray iron meeting has expressed this thought much better than I could. If we will just relegate to the background our own personal pride and peculiarities, and place the uniform cost-finding plan under the direction of someone who is intelligent and qualified to guide us in these matters, we will find that it is the greatest investment we have ever made.

We nonferrous men endeavored last year at the A. F. A. meeting in Chicago to capitalize some of the fine things the iron and steel people have worked out, used and found profitable. Mr. Runge made a valuable talk to us at that time and pointed out these same things that we are discussing. He even passed out the simplest kind of a problem, giving all cost figures, I believe, except indirect expense, and I recall that the costs we figured on that job varied by at least 100 per cent.

Your cost committee then attempted to get together a group of nonferrous men who would compare their costs. In other words, they tried to get a group which, although the members might all be operating under their various individual cost methods, would have their cost data reduced by one individual to a common denominator so as to get a comparative report. This group attempt has worked out very well, and its organization and methods will be described by Mr. Humphrey.

C. S. HUMPHREY:* Beginning with the Chicago convention last year, and even before then, I had been approached on the subject of uniform cost-finding methods for a nonferrous foundry. I did not get much information on it and, in fact, I used the same argument that has been used on me a number of times since. I said:

> "We are not a jobbing foundry. We do not quote on outside work. We have a cost system for the costs of our own castings. What good is it going to do me if I get a sheet once in a while showing that our costs are 50c a pound, those of someone else 38c a pound and those of someone else 24c a pound? What I want to know is, how can we reduce our costs with the equipment we have?"

This will give some idea of how little enthused I was when I went into the meeting in Chicago last year. Probably many foundrymen who were there will remember that we talked a while and did not seem to accomplish anything. It was finally suggested that those in authority to speak for their respective companies should convene again after the main meeting.

I trailed along with some of those who appeared enthusiastic—there were about 20 or 25 left out of some 250 at the main meeting.

B. W. Grafton of the Rock Island Metal Foundry, Rock Island, Ill., was appointed temporary chairman to see how many firms he could interest in the proposition. It so happened that the representatives from Iowa, Illinois and Indiana predominated at that second meeting, so Mr. Grafton corresponded with them and finally called another meeting for June 10 at the Blackhawk Hotel in Davenport.

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*Westco Chippewa Pump Co., Davenport, Iowa.

I was still only lukewarm, but when I found that members were coming from Rockford, Des Moines, Peoria and other places 200 miles or more away, and since my home is in Davenport, I could think of no very good reason for not attending. There were about 16 present, representing a dozen or so foundries, and every man looked over the rest of those present and decided that we were all in about the same fix. None of us were interested in selling castings for less than the cost of producing them.

E. B. Hazen of the Brass Foundry Co., Peoria, Ill., was elected chairman, I was picked as secretary-treasurer, and we also elected three directors: R. R. Monroe of the Des Moines Machine & Foundry Co., Des Moines, Iowa; J. S. Randall of the Rockford Brass Works, Rockford, Ill., and Mr. Bloom of the Aluminum Mfg. Co., Moline, Ill.

I will read the following high spots from the minutes, to give some idea of how we began:

> "The name of this organization is The Nonferrous Foundrymen's Association.
>
> "Its purpose shall be the study of uniform cost-finding methods for nonferrous foundries. Selling price and profit shall never enter into the discussions of the meetings as an organization." (We steer clear of selling price. We follow up the cost, and it is optional whether you put on 100 per cent or 50 per cent for profit.)

A local certified public accountant was present, on invitation. We were a little fortunate in the fact that he was familiar with the operation of the cast iron groups, so he explained the working of this group proposition in detail and entered into an arrangement with us whereby he would compile the data from each member for a year.

About this time I became a bit more interested. I thought I could see possibilities, and I abandoned the idea that there was any difference between the costs of a private foundry and a jobbing foundry. If any group of men can get together and devise some good method of determining costs for a jobbing foundry, it certainly will fit in with a private foundry. Anything that determines accurate costs is good for anyone who has anything to do with a foundry.

The sum and substance of the whole thing is a quarterly report, which is made at the end of each three months' operations. This quarterly report is made up on a blueprint, each member is assigned a number and he himself is the only one who knows what that number is.

The costs are split up into Melt, Mold, Clean and Ship, Core Cost and Total Cost, by departments, and under each department there are from three to five or six columns showing a detailed analysis of the cost under each department, the same as outlined for the gray iron group by Mr. Carter.

Of the two rows of figures on the sheet, the upper row gives practically all there is to see about the costs. Below are additional detailed analyses of the relation of salaries to direct labor, and the fire insurance,

taxes, etc., by percentages. The pounds of good castings produced by the entire group for the quarter, and the pounds produced by each individual foundry, also are listed. Thus each member gains a picture of his standing in relation to the group by means of his percentage of the total tonnage.

By the time that meeting was over, I was considerably enthused. I was all for dashing down to the office, opening the safe and digging out my records to see what I could figure out in the way of separate core overhead, etc. The next day, after I had a chance to think the proposition over, I began to wonder if I was not letting myself in for quite a job. The information on the quarterly report sheet is quite extensive and it is all valuable information.

At first, therefore, it appeared as though we were getting ourselves into a great amount of detail, but the surprising part of it is that that is not the case at all. The backbone of the whole system is splitting the foundry into Melt, Mold, Clean and Ship, and the Core Departments, which plan the majority of foundries probably are following now, at least to some extent.

It is surprising to find how much of the balance of the information seems to follow automatically, once the departments are established. If a certain charge has to be made somewhere, it must go in one department or another. Or, if the charge happens to be for an item used in two departments, it is split and a proportionate amount is charged to each department, depending on how much is used in each.

As to the benefits—"What am I going to get out of it?"—I would place the subject of Overhead first. In our own plant that was our weakest point and, naturally, that is the place where we reaped our first benefit.

There is no question about the fact that the uniform cost group certainly promotes the study of that necessary evil which we call Overhead. The way it is applied—the figures obtained and the variations between various plants—just naturally brings up the subject of overhead and makes its importance appreciated. Its relation to costs is appreciated, and therefore its relation to profits and losses—how they happen, where and why—because each department has a separate overhead.

In the first report issued the overhead percentages varied greatly —all the way from 50 per cent to 300 or 400 per cent. We have been in the group for a year now and have had four reports, and I believe these reports from various plants are approaching a more uniform basis. This naturally leads us to believe that the members are giving the necessary attention to the subject of overhead. They are much more in line with each other now than when we began.

When I start theorizing on this cost subject, I like to consider rather a far-fetched possibility, as if it were possible to operate a foundry as an assembly proposition. Suppose that metal is bought in tin cans, all ready to pour in the mold, at so much per pound. Someone has melted that metal and charged in his costs, overhead included, and the metal comes to the foundry at so much a pound.

Suppose that the molds are bought from another concern having no relation to the metal producer. When the metal is poured in and the two are added together, the cost is obtained.

Suppose, also, with a casting which takes a core, that the core is bought from still another firm. The core manufacturing company has a rate of overhead—that is figured in the core cost. It has no relation to the plant from which the mold was purchased; they are two separate and distinct propositions. Then the casting has to be cleaned, so someone else is hired to do the work, and that costs so much more.

In other words, every department in the foundry—considered as a complete manufacturing plant, in so far as they are equipped to turn out a product—has individual and separate manufacturing expenses. To a certain extent they are not connected and do not have much relation to the other departments until one gets to prorating general overhead, etc.

At these meetings there is opportunity to take up any question desired, and everyone gets the benefit of any point brought out. For example, a man may have made some phase or other more or less of a hobby, or he may have made a special study of some certain point in the determination of costs. While he is spending his time on that, perhaps he has neglected something else.

He goes to these meetings, brings up his subjects and perhaps finds that someone else has devoted his time to another subject. Merely by comparing experiences, everyone gets a great deal of free, valuable information.

One rather interesting experience related by one of our members is, I believe, quite out of the ordinary. He received two or three of these reports and prided himself on the fact that he was always low on salaries. No one could ever come near him on the salary item as related to his direct labor.

About his fourth report, he was rather high on direct labor, so he went back through his previous reports. Now he has come to the conclusion that he was too low on salaries. He has figured out that, if he would spend a little more on salaries, he would reduce his direct labor through supervision and administration sufficiently to more than save the difference that he might spend in supervising and getting his direct costs down. He got that from the reports.

The quarterly report also acts as a gage on effort and spurs one on to greater accomplishment. If a foundryman gets an idea he can do a certain thing in some department because someone else is doing it there—say, on a cost per pound of 1.5 cents, or on a certain overhead rate—and he begins to devise ways and means of doing it, it is a source of gratification to see his number on the report showing considerable improvement. Again if he is accomplishing anything, when he gets his report at the end of three months it may back him up or it may show him that he has not produced the results wanted or expected.

In our own experience we have had the benefit of four reports, and we have devised ways and means of reducing our melting cost, our

molding department overhead and our cleaning costs. Until we began getting these reports, we had no target to shoot at—we had no other figures with which to compare our own.

We might have thought we were going along pretty well, but when we got the reports of what other foundries were doing, we began to scratch our heads and figure out a few more places where we could save money. The saving thus effected is enough to pay for these reports for several years in advance.

It is not our theory that uniform cost groups will eliminate all the evils of big variations in price. We do contend, however, that any group of foundrymen who will get together and compile their costs on this uniform basis will naturally get to thinking and estimating their jobs on this uniform basis on which the reports are turned in. This, of course, will bring us to the point we eventually want to reach, namely, this uniform basis.

"Uniform" costs, of course, does not mean "the same" costs. We are not going to attempt to reach that point, because we have no desire whatever to try to get the same costs.

We always will have different costs, and we always should. Those differences in costs will be legitimate and will actually exist in the foundries. They will not depend on the estimator's aptitude with a pencil and paper—they will come from the records.

Some of the variations in prices quoted are enormous. I believe we can all agree on this, that if the various estimators were estimating their costs on the same uniform basis as outlined in the gray iron cost system presented by Mr. Carter, we could not have such large variations in prices quoted.

CHAIRMAN J. L. WICK: Mr. Humphrey has rendered us a fine service by taking the suggestion and working out this plan with his associates. They have been repaid, as he testifies, by securing some very valuable assistance which has permitted them to reduce several cost items.

WM. E. PAULSON:* We have been struggling along trying to get a cost group started in our territory, which is not a very fertile ground for large production plants. Chairman Wick's opening remarks have a strong bearing on the selling price of castings in our territory, or in any other territory, for that matter. Costs mean nothing to concerns such as those Mr. Wick has had occasion to look up through the financial agencies.

He mentioned one house that had some $130,000 in liabilities and which is not now operating and has not been for some time—that they are going to meet with creditors and make an adjustment on a 50-50 basis. I know of one particular concern that has the happy faculty of doing that; in fact, they have done it three times in the last ten or twelve years.

Those of us who know our costs, or think we do, find it pretty hard to compete with foundries which are able to operate in that manner and who have developed that sort of technique.

*Thomas Paulson & Son, Inc., Brooklyn, N. Y.

CHAIRMAN J. L. WICK: That is why I tried to bring out the point that I feel we need the cooperative effort of those who sell our members their various materials. They take our money; if they are not helping us to acquaint ourselves with our particular problems and how to solve them, while at the same time they are supporting by contributing material to those who are not fit, it seems to me that the burden is on us to arouse them to a sense of responsibility.

This particular concern I referred to, after taking business from many of us, finally had to admit that they were insolvent to the extent of $130,000. If that was principally for metal, I am going to pay my share of that insolvency.

Not only have I been deprived of some business I might otherwise have had, but if I buy metal from the same firm which sold metal to this competitor of mine, then they are going to add part of their loss onto their cost to me, if they know their costs. This has such a direct bearing on all of us—not only the foundrymen but the metal men and everyone connected with the industry—that we should all be sure we do know our costs. It should be the accepted thing.

I believe we are really making progress. Sometimes I feel that Providence has certainly been kind to the foundryman. Providence has permitted us to carry on in spite of, you might say, our ignorance. However, I do not believe this industry will continue to enjoy that special beneficence, because we are pretty well organized now. We do not have great undeveloped resources and new territories to open up. Where once there used to be only one foundry to a community, today there are perhaps half a dozen or a dozen, so that we simply must know our costs.

E. T. RUNGE:* I believe this cost group is getting results. They have stayed together for a year and, if they go on for another year, continuation of an idea must increase the benefits. It is when they stop before giving it a practical trial that the good is minimized. I have never seen a group which operated together for more than two years that did not find it a very paying proposition.

C. S. HUMPHREY: Probably some foundrymen who are operating efficient cost systems do not think they would get much benefit from this group. Perhaps their cost systems are exactly on this basis, they would not change a thing if they went into the group and they wonder what they could get out of it.

The benefit they can derive from this organization is to get their competitors into the group also. It is the man who has no cost system that we want in this group. We want him to compute his costs the same way the rest of us do, so that when he goes out to bid on a job, he will not quote prices 25 per cent under what should be quoted.

E. T. RUNGE: During the war the government organized the pump companies into a group—there were some forty companies in the group. They compared their costs quarterly, and someone was engaged to handle the costs and do the work for more than two years .

*E. T. Runge Cost Co., Cleveland.

One of the companies, located in Ohio, came before the meeting and said:

> "Gentlemen, there is nothing that we can gain in costs by joining in this movement. The method you have recommended and adopted we had installed in our plant by the same person you have engaged, and we are still using it and are going to continue to use it.
>
> "According to the figures given us, we are asked to pay one of the largest assessments; but we are going into this thing, not because it is going to help our cost method, but because it will educate some of our competitors who do not know what they are doing. We are going to come in and pay our share, and we are willing even to pay our share if necessary to help get our competitors' business on a stable foundation."

CHAS. DONATH:* The Fitting Brass Manufacturers have an association composed of about fifteen leading fittings manufacturers, brass manufacturers, in the country. At a meeting some two months ago we came to the conclusion that it would be a very good thing for our association to concentrate more on a cost system for our group, knowing that there was an international nonferrous group.

I was appointed one of the committee on costs, and while we have accomplished no definite work along this line up to this time, we are now getting to work. If we can be of any help, or can hook up with this movement as a body, in a way that you believe will further the movement, I shall be very glad to bring this up and recommend the proposition at our next meeting.

CHAIRMAN J. L. WICK: That would be very fine, but I think that, inasmuch as you are a member of the A. F. A., the new administration perhaps should recognize your connection with the fittings group and capitalize it when they build up their nonferrous cost group.

WM. A. ULLRICH:† Having had experience in providing an accounting plan for one of the largest electrically-equipped steel foundries in the country, I believe some phases of this subject should be given careful consideration.

While we are talking about detailed costs, pure and simple, we are forgetting the causes of these costs. We equip and employ a plant to produce castings. How many foundrymen have ever computed what portion of the total cost of operating the various activities of this plant is chargeable to the service or nonproducing departments?

In one instance we found that overhead amounted to approximately seventy per cent of the total cost. In other words, direct labor and materials comprised only 30 per cent of the total cost.

Correctly computed, the overhead in many foundries will amount to more than 50 per cent of the total manufacturing cost. In many cases

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†Certified Public Accountant, Dayton, Ohio.

the larger amount of this overhead is the cost of operating these non-producing or service departments. With the wider use of machinery, the amount of overhead is increased, and the problem of its distribution becomes more involved.

Is it not important that we control these service or non-producing factors? If we simply look at costs, without considering the causes of these costs, and without planning for their control, we lose sight of the most important phase of industrial accounting.

While talking with Mr. Mitchell, he raised the question of why only two plants in a certain group of foundries had cost systems worthy of the name. I replied that I believed it was because of the manner in which the cost-accounting plan had been presented. We found this fact to be the case in the foundry to which I refer.

A very prominent engineer endeavored to compute costs on an average weight of the product which this foundry was expected to produce in a four weeks' period. Under the use of such computation, one may guess how great was the discrepancy when the physical inventory was taken.

We said to the management: "You do not sell your wheels on the basis of average weight but by individual pattern numbers, and, although you have as many as 3,500 different patterns, it is necessary to cost your sales by pattern numbers. There can be no accurate plan of averaging the cost prices of your product."

This foundry is now computing the actual cost of each pattern of wheel made and sold, with less effort and with much more satisfactory results than under the method of so-called averages.

In our plan of industrial accounting we set up a group of accounts for the labor and expense items of each "factor" used in production. A "factor" means any activity, function, or department. Factors are of two kinds: Those that render a service, and those that produce the product.

Service departments in the foundry to which we refer are: Occupancy-Buildings, Steam Generating, Power and Light, Factory Administrative, Materials, Shipping, Cranes, Compressed Air, Plant Maintenance, etc.

The Production Departments are: Core Making, Molding, Melting Furnaces, Castings Cleaning, etc., in the foundry proper, and six separate departments in the large machine shop.

Under this plan of detailing the cost of each department, the cost of each factor may be viewed independent of all other factors, with the resultant controlling of costs while they are in the making. For instance, when the cost of producing compressed air in this foundry increased, the management could immediately put its finger on the detailed items causing the rise.

We simplify the identification of our manufacturing accounts by numbering a complete list of primary or basic Factory ledger accounts from "01" on up. These primary accounts are usually arranged in the following order: Labor or Payroll, Supplies and Service, and Fixed Charges. The list of departments is also numbered.

Then, by prefixing the department number to the individual primary accounts peculiar to that department, we provide an identification num-

ber for each item of labor and expense. Under this plan we may have as many as 99 items of labor and expense and 99 departments, without using more than four figures to indicate any charge to any department. Thus the few recurring expense items and the main departments are readily memorized.

In the foundry under discussion we have more than thirty different activities or departments. It seems hard to believe there are that many in a foundry, doesn't it? However, if a plant is carefully departmentalized, it will be surprising to learn how many different activities are being operated before the production of castings is even begun.

To illustrate a method of comparing costs under this plan of industrial accounting by production factors, let us suppose that one foundry in a certain group is producing its own compressed air while the others are not, or that another foundry is generating its own steam and the others are not, and so on with other service departments.

It is evident that among this group of foundries, completed costs are composed of the results of different activities or departments, and as each of these different activities is not operated in each of the foundries of the group, the only correct bases for comparisons are the costs of the individual activities.

For example, all of them may compare the cost per square foot of occupying the buildings in which they operate. Those that produce compressed air may compare the cost of each cubic foot of air produced; those that generate steam, the cost of pounds of steam generated, etc.

This basic comparison may be carried through all the Service and Production departments. Such a comparison of department totals need not disclose the detailed amounts of expenses.

Although a group of foundries may derive benefit from discussing completed costs, the greatest gain will come from this comparison of basic department costs. If it is costing one plant 18c a square foot to occupy its building, while it is costing another 25c a square foot for the same service, a comparison of the detailed items of Occupancy expense will indicate the causes of this difference. Similar comparisons may be made of all other departments, because related items of cost are classified in a like manner for similar activities.

Again, each plant may compare its departmental details with budgeted amounts for the current plant capacity or with previous periods. In this way the efficiency of each factor of production may be closely watched and controlled.

This plan furnishes a complete perspective of the operations of the entire plant. While the activities of each department are shown as if it were the only factor in operation, at the same time we see its proper relation to other departments.

This plan gives a continuous and detailed check on operating efficiency. It supports and records the results of research engineering. It furnishes the information necessary for the proper executive and managerial control.

Of course there are many details which I should like to describe, such as the cost of melting, sand handling, cranes, maintenance and

other items of operations, because we have "whipped" the problem of accounting for these factors, and the procedure would make an interesting discussion. We have secured some very satisfactory results, both in the accurate costing of the product made and in the more important phase of cost control.

S. R. FRANCIS:* In one particular case that I came across while studying oue of our competitors whom we recently absorbed, regarding the production of a certain casting, the sales manager of the organization made this statement: "We only use 9 cent metal in that particular line of castings."

I replied: "Just recently I had the pleasure of checking up a casting in that particular factory and on that particular job, and the actual metal cost was 14¾ cents a pound."

Yet that organization was selling the castings on a basis of using a metal costing nine cents. That is just a broad case of not knowing one's costs.

In our own foundry we specify to our melting department each particular class of metal that goes into formulating any alloy. If we are making a partial scrap mixture, our metal department knows exactly what must go in. They turn in a report to our cost department which shows the exact proportions, and at the end of every month we can tell exactly the cost of the different grades of metal used in the different castings.

CHAIRMAN J. L. WICK: Regarding this concern to which you referred, Mr. Francis, I presume that if you had not taken them over, no doubt the sheriff would. We have these things with us, just like the boils or the torment of Job, and we have to bear them. But do not get excited over them.

When we establish a cost system and know it is right, we must stand by it. It hurts when a real account turns us down for this type of competitor, but if we can hang on—and I believe we can—at least we can keep what we have rather than dissipate it in serving him. And eventually we will see the day roll around when we are reinstated.

One of the fine things a cost system does is to stiffen up the backbone, but at times it is pretty hard on the sales department. We have had some experience along that line.

It so happened that we adopted the cost system immediately after the Detroit A. F. A. convention, and the reaction of the salesman was evident. He would come in and say, "Well, So and So can buy that for so much," or "So and So will furnish that for so much. You had better throw that damned cost system in the lake."

We stood our ground, however, and managed to carry on. It has been surprising to me that there is apparently so little real interest in knowing our costs.

N. K. B. PATCH:† I want to emphasize the remarks on the need of a cost system in the nonferrous industry from a somewhat different

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angle. It seems to me that the competition establishes a need for a cost system. There is no doubt but that we must get down to brass tacks and know our costs in order to be able to compete and get our fair share of business.

A cost system is also a further help and a very vital one in enabling us to determine where we are failing in being efficient and in growing to be the kind of manufacturers that are going to survive. Those men who have been efficient, those industries which have been sufficient, have lived through times of stress and hard times. Those that have not, have fallen by the wayside, resulting in such reports as referred to by Mr. Wick.

Therefore, the cost system serves a two-fold purpose. It enables us to see how we are progressing in our effort to become more and more efficient, and it enables us to know what our materials are costing us. I prefer the word "parts" rather than "castings." I believe we are makers of parts; the term "castings" is too ambiguous.

We are making parts for a certain piece of machinery or something else, and we must sell them at a price that will enable us to get the order. But we cannot do that without having some yardstick with which to measure our own efficiency, our own ability to manufacture each and every step of the product at a minimum and a reasonable price.

The big thought to get is that a cost system is a starting point. A cost system enables us to be judges of what we are doing in comparison with others, and how our own business is operating each month compared with the last month, or compared with the same month last year.

Continuous Melting from Cold Stock of Gray Iron in Electric Furnace

By N. L. Turner,* Ottawa, Canada

Abstract

In the plant of the Beach Foundry, Ltd., producing stove parts, a point was reached where, with cupola melting, it was necessary to extend floor space to take care of the production. By installing an electric furnace for melting, a continuous flow of iron was obtained and the need of extra floor space for the day's run of molds was overcome. This increased production per floor and decreased the cost of molding equipment. At the same time, by the use of all scrap metal, the cost of iron at the spout has been reduced, production increased about 25 to 30 per cent and the flexibility of the method has proven very valuable in speeding up production and coping with rush orders. Charges consist of cast-iron borings, shop scrap and steel clippings plus alloy additions. Cost of iron at spout is about $23.71 per ton. Methods of charging and melting are described, and the ideal electric-melted iron analysis is given.

1. For the past twenty-one months a 3-ton electric melting furnace has been in successful operation at the plant of the Beach Foundry, Ltd., of Ottawa, Canada, whose manufactured products of coal and wood stoves, furnaces, gas and electric ranges are sold throughout Canada and British possessions. This is the first installation in America of an electric furnace as a melting unit for the production of stove-plate castings.

2. A point had been reached at which, on cupola operation, where melting was not continuous, it would have been necessary to materially extend floor space in order to cope with the production necessary for the ever-increasing business. As this was undesirable, a system had to be evolved whereby a greater volume of castings could be obtained from the same floor space

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3. As 20 to 30 tons were not considered high enough tonnages to merit continuous cupola operation, a more adequate means had to be devised. After due consideration it was felt that an electric furnace as a melting unit would be the most feasible way to accomplish the desired results. The 3-ton furnace, therefore, was purchased.

Electric Furnace Installed

4. The main objective has been successfully reached through continuous operation, as the same floor space and molding equipment can be used a number of times during the day. This considerably increases the production per floor and, at the same time, materially decreases the cost of molding equipment necessary.

5. Being one of the first electric furnaces to be installed in this type of plant, a considerable amount of research work was necessary to determine the analysis of iron most suitable for stove-plate castings, since there are considerable physical differences between cupola and electric-furnace iron of the same analysis. This involved the working out of a standard charge with the raw materials available, and also the determination of the best pouring practice to be followed in the shop.

Advantages of Continuous Operation

6. After twenty-one months of successful operation it may be said safely that the original objectives have been attained, and through improvements made in practice, that the electric furnace has proven to be an ideal melting unit on this class of castings.

7. There are at least three distinct advantages which have been gained by continuous operation, as follows:

(1) Production of castings has been increased 25 to 30 per cent under existing conditions, without sand-conveying equipment and working only one shift a day.

(2) The cost of iron at the spout is considerably less than previously obtained with the cupola.

(3) The flexibility of the method has proven very valuable in speeding up production and coping with rush orders.

8. The superiority of the electric furnace as a melting unit is forcibly displayed in its capacity for handling charges that could only be melted in the cupola with heavy losses.

Charges Used

9. It is now our practice to melt approximately 40 per cent of cast-iron borings, which we find an economical and a low-loss raw material.

10. Cast-iron borings in our district can be purchased at a much lower price than other scrap metal, and, with the necessary additions of ferrosilicon, ferrophosphorus and ferromanganese, can be converted into a high grade of gray iron at a much lower cost than previously could be obtained with cupola iron.

11. The disposal of steel clippings from our sheet-steel department formerly caused us a considerable amount of trouble, for the expense of baling and shipping rendered them valueless, forcing us to dispose of them by the simple expedient of dumping them on the scrap heap. However, with the installation of the electric furnace we have been able to treat them as a raw material, making them part of our first charge. It is inadvisable, however, to melt them in large quantities, owing to their tendency to reduce the carbon content.

Eliminates the Use of Pig Iron

12. For the twenty-one months of continuous operation we have not used a pound of virgin pig iron in our charges, producing at the same time a better quality of gray iron than that obtained in the cupola, where a high percentage of pig iron must be used.

13. Of course, one of the deciding cost factors is the power. In districts where power can be obtained at a reasonable rate, the cost of iron at the spout would be lower than that of the cupola. In any case, however, at equal cost, a considerable saving is effected through outside conditions.

14. It may be added, however, that kilowatt-hour consumption per ton is higher under continuous operation than batch melting.

15. The cost summary of Table 1, taken off our figures for a typical month, show some interesting details.

Operating Costs

16. It will be noted that the percentage of foundry returns is high in comparison to the total melt. This is due to the

nature of our work, which is light stove plate. A large percentage of it is made on machines from match-plate patterns, where the sprues and gates almost equal the weight of the casting.

17. Attention will also be drawn to the fact that the cost of power per ton is high in comparison to the favorable rate we have. This is due to operating the furnace under its capacity with a lowland factor of 37.05 per cent.

Table 1

COST SUMMARY—OPERATION OF ELECTRIC FURNACE FOR ONE MONTH

Raw Materials:	Lbs.	Cost per ton	Total cost	Total cost per ton
Stove plate	102,095	$12.50	$ 637.50	
Borings	234,450	10.00	1,172.50	
Steel scrap	27,455	.....	.....	
Foundry returns	323,285	13.00	2,100.80	
Additions	8,290	.....	.....	
Total	695,575		$3,910.80	$11.25
Additions:	**Lbs.**	**Cost per lb.**	**Total cost**	
Fe Si	6,350	$ .03	$ 190.50	
Fe Mn	750	.04	30.00	
Fe Ph	1,190	.06	71.40	
Coke	13,200	.006	79.20	
Total	21,490		$ 371.10	1.07
Labor			$ 397.72	1.14
Power			1,825.55	5.25
Electrodes				2.09
Refractories				.60
Water				.11
Laboratory				.50
Interest on investment, and depreciation				.57
Melting loss				1.13
TOTAL COST OF OPERATIONS, PER TON				$23.71

18. A 3-ton furnace gives the best efficiency when operated at 2000 horsepower and at least 65 to 70 per cent load factor. This would decrease the cost of power 50 to 60 per cent. We contract for our power at 11,000 volts on a flat-rate basis of $23.00 less 10 per cent and 5 per cent per horsepower per year

(net $19.67); but, while operating under capacity, we have a composite rate as follows:

Service charge	@ 80.	cts. per h.p. per month
First 50 k.w. used in month.....	@ 1.3	cts. per k.w. per month
Second 50 k.w. used in month....	@ 0.9	cts. per k.w. per month
Balance of k.w. used in month....	@ 0.12	cts. per k.w. per month

Total bill subject to 10% and 5% discount.

19. The low cost per ton shown on the cost statement is, undoubtedly, due to the low-priced raw materials available in this locality. One of the main factors contributing to the greatly reduced cost is the lack of necessity of using pig iron in our charges. As No. 1 pig iron at present is $25.00 per ton, f. o. b. Ottawa, this can be recognized readily as an important cost item.

Melting Practice

20. To maintain the continuity of the continuous operation, an initial bath of iron must be built up before the continuous charging and tapping may take place.

21. After the last iron is tapped out, the pits are cleaned, the furnace bottom is patched and the first charge—consisting of gangway pig, foundry returns, stove-plate scrap, cast-iron borings and steel clippings—is charged into the furnace.

22. At a fixed time, the melters come on duty and commence to melt down the first charge, consisting of three tons. On completion of this operation and when the iron is up to temperature, the furnace is slagged off and more borings are fed in, in suitably sized charges, until a bath of nine tons is built up.

23. In charging the feed charges, a division is made and two separate piles are placed, one on each side of the charging door, so that the melter and his helper can feed them into the furnace without loss of time.

Metallurgical Analysis

24. On completion of the melt-down of the original bath, a test bar is poured and a complete analysis is taken before any iron is tapped. This enables the metallurgist to correct discrepancies in analysis, and maintain a constant quality of iron.

25. When the iron is passed by the chemist and is up to temperature—the temperature being taken by an optical pyrometer—the first ladle is tapped out. The first bull-ladle of iron is usually tapped out at 7:00 a. m., to pour off any molds that

have been left from the day before or any overtime molding accomplished the previous evening. Sometimes it is necessary to tap out several bull-ladles in succession, to meet with shop requirements, but this serves to stress the advantage of the flexibility of the system in providing iron at any time.

26. After a tapping has taken place, a feed charge is charged in, and this operation of tapping and feeding is continued until the necessary amount of iron is obtained for the day's cast.

Feed Charges

27. The feed charges consist of foundry returns and stove plate scrap, which do not require the addition of any alloys. It is a good practice, however, to mix a charge of foreign stove-plate scrap with foundry returns, because it is found that the former has a tendency to oxidize the iron and reduce the carbon content. With each feed charge, about one per cent of ground coke is added to take care of any loss of carbon that may take place in the melting.

28. Our usual feed charges under present requirements consist of approximately 1100 lbs. of iron, which takes between 15 to 30 minutes, depending upon the power input. About 1400 lbs. of iron are tapped out. This, however, depends upon shop requirements.

29. The minor operations, such as daubing the bull-ladle, repairing the spout and grinding the coke, are taken care of by the melter and his helper, who can attend to these in conjunction with the original melt-down.

30. The bull-ladle is heated up in the morning by means of a gas blast before any iron is poured into it. This obviates chilling the iron by means of a "green" ladle.

31. The shop is divided up into pouring stations, the bull-ladle going to each station according to schedule, or as desired. The stations are signaled by means of a whistle at the furnace, so that the molders and shaking-out crew designated to that station will be ready for iron.

32. A careful temperature control is kept throughout the day. Every bull-ladle of iron has to pass the temperature test before it is conveyed to the pouring station. The ability to control the analysis produces a grade of iron which is almost unvarying in its consistency.

Ideal Analysis of Iron

33. We have found the ideal stove-plate gray iron analysis, for iron melted in an electric furnace, to be within the following ranges:

Carbon, per cent	3.25 to 3.35
Silicon, per cent	2.75 to 2.85
Phosphorus, per cent	.60 to .70
Manganese, per cent	.45 to .60
Sulphur, per cent	less than .09

34. With electric-furnace stove-plate iron, it has been found necessary to keep the silicon higher than that of cupola iron, and it should never drop below the minimum outlined above. During the day, however, there is a slight increase in silicon, undoubtedly picked up from the slag and furnace bottom. This, however, can be controlled by the addition of some low-silicon raw material, such as borings.

35. During the experimental period, considerable difficulty in keeping up the carbon content was experienced, but this was overcome by the use of the proper amount of ground petroleum coke.

Refractories

36. On continuous operation the refractories do not give so high a tonnage as on batch melting, but the following figures may be considered satisfactory:

Roof, about 650 tons
Lining, about 850 tons

37. Considerable difficulty was experienced at one time in maintaining the bottom; but, through improved practice, a method of patching the bottom has been evolved which has proved very satisfactory.

DISCUSSION

ORAL DISCUSSION

H. M. LANE:* Last year we put in an electric furnace at a plant in Michigan which makes chemical and baking machinery. They have had a great deal of trouble there with certain castings, due to tiny pin holes

*H. M. Lane Co., Detroit.

which subsequently act as a center for corrosion in the machine in which the castings are used, causing the work to be thrown out.

In cupola iron they produce a casting that has tensile strength of 40,000 lbs. per sq. in., from a 30 per cent steel mix; but when the castings were machined and polished, as high as 50 per cent of the castings had to be thrown away.

With the electric furnace they have the same tensile strength, approximately the same brinell, but a very much better machining condition. Also, not a single casting has been thrown away since the electric furnace has been in use since last fall, showing that it is the fine carbon structure that gives a different type of iron. It seems also to be gas-free, so that they get no trouble from that source.

Two other factors about this installation may be of interest. It is now run off-peak load, starting at 4:00 p. m. and running until midnight. The workers like the shift because in the winter it allows them to sleep a little longer in the morning, while in the summer it allows them to work in their gardens.

The furnace is used on small jobbing work of the foundry, of which they have a very large amount. I have seen one man there with forty patterns for his night's work, and sometimes even more than that. With loose patterns, he would put three to six in a mold.

These six molders work all night on that job. One or two men put up floors during the day and leave them for backlogs to be poured during the night. One man runs the furnace, one man does all the pouring, cutting back the sand, shaking out the castings, etc.

The testing is accomplished by means of a test bar which they break. After the melting is done, it takes possibly four minutes or five minutes to cast one of these test bars and break it. As soon as that is done they say, "Use a little more silicon," or "Use a little more steel." They put in three or four more pieces of steel, or a trifle of silicon, and they are ready to cast.

I believe they have had only one off-heat since the furnace started.

Another interesting fact is that there is a relatively high current charge in the Saginaw district. Running off-peak load and using 50 per cent borings and 50 per cent scrap, usually without any direct steel other than that in the considerable scrap coming back from the cupola—which has 30 per cent steel in it originally—the method is costing the same as it costs in the cupola. My memory of their costs is that two months ago the cost of castings in the shipping room was 3.6 cents a pound for this jobbing class of work.

F. D. O'NEIL:* Mr. Turner, what about the machinability qualities of the gray iron you are making?

N. L. TURNER: We raised the silicon about 25 points over the cupola iron to improve machinability. We have only a few drilling operations.

F. D. O'NEIL: You spoke of the temperature of pouring this iron. Have you any figures as to whether that is a higher pouring temperature than your previous cupola practice?

*Western Foundry Co., Chicago.

N. L. TURNER: It is about the same. A good part of our work is nickel-plated work, and if we pour it too hot we cut the sand. We must have a dead soft iron—a fluid iron. Annealing is not required.

Mr. Frear states that their phosphorus is down to 30 points. We keep the phosphorus up to 60 or 70 points. We have an acid lining.

F. D. O'NEIL: We have just changed our practice with a small cupola to continuous pouring operation. Our shop is not really laid out for continuous work, but we have had certain jobs where we have not had sufficient equipment to set up a full day's floor and then pour it off. Consequently, we have been running this cupola continuously and we have found difficulty in other jobs where we had sufficient flask equipment to run all day.

Due to the long heats, certain jobs were poured early in the morning and the molds would set all day. They were so dried out by the time they were shaken at night, that we have had a great deal of difficulty with our sand failures. What is your practice in that regard, Mr. Turner?

N. L. TURNER: We follow up the pouring with the shakeout. Our machine molding is all done on one side of the shop. Four machines are placed in the center of each floor, and each molder probably pours only four or five ladles at a time. The iron comes out every 15 to 30 minutes, according to the time we desire.

A. I. KRYNITSKY:* This stove-plate business is very closely tied up with the enameling of cast iron. Mr. Turner, how do you control, if you do, the maximum melting temperature in the electric furnace?

Judging from your figure on pouring temperature, which was given as 2700 degs. Fahr., I assume that the maximum melting temperature was close to 1600 degs. Cent. (2912 degs. Fahr.). If that is correct, you have superheat conditions. Superheat conditions bring very small graphite particles. These fine graphite particles, during the short enameling fire, should burn almost continuously, and blisters may result.

From this standpoint, to my mind, control of the maximum melting temperature is very important. Do you have any figures on this?

N. L. TURNER: The temperature is taken in the stream as it comes from the furnace—as it is poured into the ladle. I doubt very much if the temperature of the iron in the furnace is much higher than the figure given.

A. I. KRYNITSKY: Do you add silicon—if you do add silicon—in the furnace or in the ladle?

N. L. TURNER: No silicon is added during the day at all.

A. I. KRYNITSKY: Evidently you have high-silicon pig iron, or you have to add it.

N. L. TURNER: No pig iron. The silicon addition is made in the original bath in the morning. The cast-iron borings we are using at the present time run about 1.60 silicon.

A. I. KRYNITSKY: Do you add it in the furnace?

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*U. S. Bureau of Standards, Washington.

N. L. TURNER: Yes, in the morning—probably it is added around four o'clock in the morning.

A. I. KRYNITSKY: We have had very little success with the addition of silicon in the ladle. When we add it in the ladle the iron is quite porous.

N. L. TURNER: We find that we have a silicon pick-up during the day, especially if the iron gets a little overheated. We will pick up silicon from the slag or the furnace bottom.

WRITTEN DISCUSSION

C. L. FREAR:* Mr. Turner's excellent and instructive paper describes thoroughly the advantages of continuous electric melting in the production of gray cast iron, so that any discussion must take the form of an appendix to the data already given.

TABLE 1

PERCENTAGE OF MATERIALS CHARGED

	Per cent.
Returned scrap	45.4
No. 1 malleable pig	35.2
Steel	18.7
Ferro-silicon	0.3
Petroleum coke	0.4

ANALYSES

	Cupola per cent	Electric per cent
Total carbon	3.52	3.60
Graphite	2.80	3.06
Combined carbon	0.72	0.54
Silicon	2.31	2.75
Manganese	0.52	0.60
Phosphorus	0.75	0.30

Several weeks ago, the writer tested two sets of standard A. S. T. M. 18-inch-span arbitration bars, one cast from cupola iron and the other from electric-furnace iron. The first mentioned was made by the usual cupola practice and the second by continuous melting from cold charges in the electric furnace, the total percentage of materials charged during the day being as shown in Table 1.

The graphitic carbon in the electric-furnace iron was higher, as might be expected from the higher silicon content.

These two lots gave the physical properties shown in Table 2.

*Metallurgist, De Laval Separator Co., Poughkeepsie, N. Y.

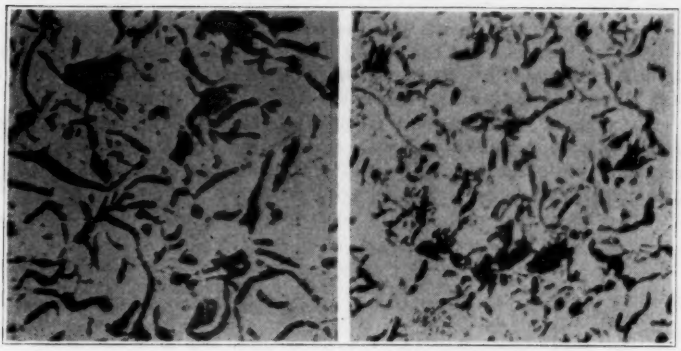

FIG. 1 (LEFT)—CUPOLA IRON. UNETCHED, 100X.
FIG. 2 (RIGHT)—ELECTRIC-FURNACE IRON. UNETCHED, 100X.

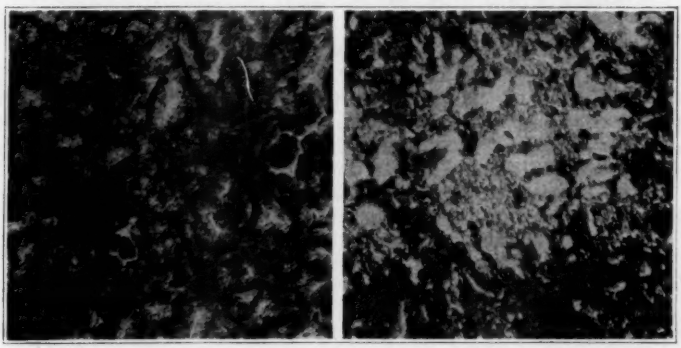

FIG. 3 (LEFT)—CUPOLA IRON. ETCHED IN 2 PER CENT HNO_3, 100X.
FIG. 4 (RIGHT)—ELECTRIC-FURNACE IRON. ETCHED IN 2 PER CENT HNO_3, 100X.

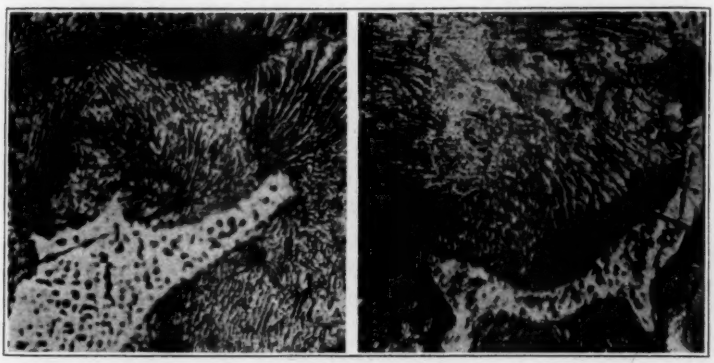

FIG. 5 (LEFT)—CUPOLA IRON. ETCHED IN 2 PER CENT HNO_3, 1000X.
FIG. 6 (RIGHT)—ELECTRIC-FURNACE IRON. ETCHED IN 2 PER CENT HNO_3, 1000X.

The transverse properties of the electric-furnace iron were considerably better than those of the cupola iron. Although the brinell hardness of this iron was lower, as shown by the drill test, the machinability of this metal was considerably lower than that of the cupola iron.

A study of the structure of the two irons showed that, with the exception of the graphite and some eutectic, the cupola iron was entirely pearlitic, while the electric-furnace iron contained considerable ferrite arranged in dendrites.

The higher strength of the electric-furnace iron, therefore, must

TABLE 2

PHYSICAL PROPERTIES

	Cupola	Electric
Load (A. S. T. M. 18-inch-span), lbs....	1685	2288
Deflection, in.	0.24	.24
Tensile strength, lbs. per sq. in.	18,908	23,990
Brinell hardness	202	179
Drill test, Rev. per in.	925	1500

have been due to the smaller particles of graphite. A study of the photomicrograph of this iron shows some fairly large primary graphite particles and a much larger number of small rounded graphite particles which evidently separated after the metal was completely solid.

The chief purpose of this discussion is to show the comparative ease with which it is possible to obtain a high-strength iron with ordinary charges in the electric furnace.

Where Are the Young Foundrymen?

By S. Wells Utley,* Detroit

Abstract

Recognizing that the foundry industry, while needing trained men, has been content to go along depending on chance for providing experienced personnel, the author appeals to foundrymen to make an organized effort toward bettering the situation. No determined effort has been made to picture to young men the chances and benefits obtained from learning the foundry trade. On the contrary, the industry has seemed content to let the common opinion exist that foundry work is dirty, and unsatisfactory for our American youth. This impression must be overcome and the desired type of young men brought into the industry if it is to hold its place. Training is urged which will produce good mechanics, skilled molders, coremakers and furnace operators, as the writer believes that there are many boys who will undertake such apprentice courses if they are approached in the proper manner and are shown an opportunity in keeping with modern conditions.

1. It is the habit of foundrymen and those engaged in other industries, when a number of them get together, to discuss their troubles at length. They usually begin by saying that the industry is going to seed in general, and then take up their problems in detail. And when they have recounted their various troubles—arising from the low prices which prevail in the industry, the intense competition among themselves and the complications brought on by the advance of forging, welding and other processes—they bring up the impossibility of hiring foremen, melters and molders, and deplore the passing of foundry craftsmanship.

2. Even those foundrymen who have established their plants on a production basis, with a large proportion of machine work, are nevertheless handicapped by the lack of men to supervise and lay out the work.

*Vice-President and Manager, Detroit Steel Casting Co.

3. It is stated generally that modern young men are weak, lazy and effeminate, that all of them want to work in banks, sell bonds or insurance, or do something which permits them to sit at a desk and wear a white collar. It is pointed out that all are afraid to soil their hands, and that they think about nothing except amusement and the lighter forms of enjoyment.

4. The so-called old-style young man—stout, bright, alert—is said to have passed out of the picture. It would appear that no young man can be induced to enter the foundry trade under any circumstances whatsoever.

5. Much of this kind of discussion is based on facts. It is true that very few boys are going into the foundry industry at the present time. It is unfortunate, of course, that young men do not rush into the foundries; but isn't it equally true that foundrymen as a rule make no effort to attract young men?

6. I have seldom heard any of them make definite plans for solving the problem. When they have vented their disgust with the modern generation, they are through. The attitude quite largely is, "Well, if the young men won't come into our business, we shall get along without them. We have managed so far and we shall continue to do so."

7. They assume, quite largely, that the fault lies entirely with the young men, and few of them have conceived the idea that possibly foundry management is partly at fault. And yet, no industry and no organization can be secure and healthy which does not constantly attract young blood to itself.

8. A strong human element must always be fundamental to every industry. We may build the finest foundries in the world, equipped with the newest and best furnaces and cupolas, the best of molding machines, the most efficient sand-handling equipment; but unless this wonderful plant is operated by first-class foundrymen, it will not succeed.

9. It is true that self-trained men have successfully operated old-fashioned foundries in days gone by, but the very complexity of our modern equipment, and the multiplicity of our requirements, call for a training unknown in former times. While our fine modern equipment is of great help to all of us in the foundry industry, it will not do away with the necessity for careful and intelligent training. After all is said and done,

man is still superior to the machine—man still controls the machine; not the machine, the man.

10. The young man is apt to think of the foundry as being an unpleasant place in which to work. He conceives of the labor as being hard, of the necessity for constantly working in and with sand as being unpleasant, and of working conditions as being less satisfactory than in some other industry. To some extent his objections are valid, but a shovel of sand is no heavier than a forkful of hay, and the conditions in the modern foundry are far less objectionable than those in many other lines of industry.

11. Modern engineering, with its sand-handling equipment, is constantly lightening the load, and modern thought is constantly improving conditions under which we labor. And, on the other side, we have an industry full of problems and full of interest, which, recognized and properly interpreted to youth, will do much to counteract this feeling.

12. Where can you find an industry whose roots go back so far into the foundation of society as the casting of metal? What other industry presents so many problems to the inquiring mind—problems of mechanics, problems of physics, problems of chemistry and metallurgy, problems of gases, problems of fluids and problems of solids, and of the forming of one from the other?

13. What other industry retains so much of individualism? The production of a jobbing casting, at least, is an art instead of a stereotype process, more like the painting of a picture or the chiseling of a statue than the mechanical process existing in some trades. In what other industry do we so easily feel the pleasure of creating that which is new, that which because of our efforts exists now, but has never existed before?

14. If we who live by the industry have never appreciated its glorious side, why should we feel surprised that youth, which sees it superficially, should miss it? Why should we blame the young man for our failure to point out to him the worth-while parts of the industry in which we are engaged?

15. It is no doubt true that modern methods in manufacturing, including the foundry, have substituted machines for hand skill in many directions. At the same time, it is true that in every industry and in every foundry, high-grade mechanics are required to supervise, direct and lead the work; and the need for

such high-grade men is even greater now than it was in the old-style industry.

16. It also is true that in our jobbing foundries there will always be quantities of work in which the machine can be used only to lighten physical labor, and where the skill of the trained artisan must always be relied upon to produce satisfactory results.

17. Where are our young foundrymen? By and large, there are none. The best foundrymen are men of middle age or older, and yet no industry can continue unless it builds up a generation of young men.

18. We must bring large numbers of young men into this industry, we must show them its attractive features, we must train them into the knowledge and skill which we possess—or we shall find ourselves falling behind in our ability to satisfy the increasing demands necessary to meet society's onward progress.

19. What have we done to attract young men? As an organized industry, we have done little or nothing.

20. As a matter of fact, I doubt whether we have yet appreciated the necessity of doing anything, nor have we recognized this as a definite obligation on ourselves or our industry. Molders have come to us, in the past, largely as does the air we breathe. We haven't realized that this condition might not always continue.

21. I gladly acknowledge that there are some notable exceptions, some individual foundries and local associations which have embarked upon training programs which are a distinct credit to them. The splendid foundry school which the Cleveland foundrymen have dedicated within the last few months is a striking example of the fact that the problem is being recognized, and that steps are being taken in some quarters to meet it. But as an industry we haven't approached it with the realization that the public judges the value of a calling quite largely by the time and effort it takes to master it.

22. Few of us appreciate the intricacies of the profession of law or surgery, but we respect them because of our knowledge of the years of training necessary for their mastery. We know that the medical profession considers the training of its successors as of sufficient importance to warrant their supervising the work of medical colleges and the granting of degrees. Com-

mittees, made up of the leading medical men of the country, will sit for days in the discussion of educational problems.

23. In the engineering profession there is a large organization known as the Society for the Promotion of Engineering Education, whose only purpose is the development of training for young engineers. During the war, much time and infinite pains were taken in training our men before they were thought sufficiently grounded in their technique of modern warfare to take their place in the battle line.

24. The great trading companies and the trade guilds of the Middle Ages devoted no inconsiderable part of their time and energy to the direction of trade schools and apprentice training. Our public service institutions, our telephone and telegraph, electric light and power companies and transportation agencies expend large sums in educational effort and the training of capable employees, and no inconsiderable amount of the position they hold in public esteem arises from the knowledge of the effort being made to properly train those who carry on this work.

25. I recently heard the president of one of our railroads make the statement that, notwithstanding the tremendous gain which had come to industry through the improvements in tools and machinery, he believed that a far greater gain could be made through the improvement of human relationships. There is no better place to start than through apprenticeship.

26. I do not believe that the youth of today is essentially different from the youth of any other day. He realizes that he must face different conditions and he naturally expects to face them in a different manner; but there are still large numbers who realize that they were not born to be President of the United States—who are quite willing to become good molders if we but approach them in the proper manner and show them an opportunity in accordance with modern conditions.

27. I am not urging the training which will qualify boys for positions as foundry executives, but that which will produce good mechanics, thoroughly skilled molders, or coremakers, or pattern makers, or cupola operators. To accomplish this, we must recognize the need, we must believe in the work and the value of the results we are going to attain, and we must really want to do it and not feel that we have been pushed into it, else

we shall not be able to interest the boys and make them enthusiastic about it.

28. To be successful in this work, a company must organize on the same principle that it organizes to buy its raw materials or develop its cost figures or to handle metallurgical research problems. It must set as its goal the training of certain young men, the making in this particular department, not of molds, but of molders.

29. Just how the details should be accomplished, I leave to those who have devoted much more time to the study of this subject than I have. But I am quite sure that, in general, the time has come when we must devote thought to this question, and that when we tackle it with the energy and the intelligence of which the industry is capable, we shall not have to ask, "where are the young molders?" in vain.

(Discussion of the preceding paper is combined with that of the following paper, and will be found on page 774.)

Training—Apprentice to Foreman

By E. H. Ballard,* West Lynn, Mass.

Abstract

As the word "apprentice" literally means "learner," the author's view is that training is a constant problem in the industries, and that others besides the designated apprentices must be given consideration. Older men, given special training in molding and core making during the war, proved receptive to this instruction, and many of these men still are doing some of the best work in this foundry. Engineering school graduates, given special training, have proved a source from which higher plant executives could be developed. Now apprentices are regularly indentured in the foundry and are developing in a satisfactory manner. The author feels that training is more necessary than ever in the foundry, because of keener competition which requires a higher standard to put the foundry on a plane equal to that of other manufacturing departments.

1. The word "Apprentice" means, literally, a learner. The word is derived from a French word meaning "to apprehend," "to catch on." In our ordinary discussions of apprentice training we have used the term to designate any young person placed with skilled workmen to learn a trade.

2. My thought in referring to the literal meaning of the word is to recognize some of the young men who, during the past few years, have actually served an apprenticeship in the broad sense of the term and yet were not considered apprentices in the formal meaning of the word. When I was first approached to say a word on this subject, there flashed through my mind the thought that we are all apprentices so long as we continue to absorb knowledge, as we must of necessity be "catching on" and learning throughout our active careers.

3. As I see it, the question of whether or not an apprentice

*Superintendent, Pattern Shop and Foundries, River Works, General Electric Co.

is indentured may be left out of the broad consideration of the question. It is merely a cleaner-cut business method which appeals to the average youth in commencing his career in the business world.

Training Older Men

4. During the war we had no indentured foundry apprentices, and as we had for many years been forced to train unskilled help for much of our miscellaneous molding and core-making operations, we experienced—as did other foundries—a shortage of help of this character. We secured a number of married men beyond the draft age and agreed to teach them molding and core making, paying them a wage higher than that usually paid unskilled help and gradually increasing their wage as they progressed.

5. Today it is surprising to look about our foundries and see the large number of employes who were trained under these conditions and who still remain with us—and doing some of our very best work. This does not apply to machine molding but only to miscellaneous floor work. My contention is that these men in reality served an abbreviated apprenticeship.

6. However, I think we all appreciate that a youth in his teens, under proper guidance, would naturally develop into a better workman. We believe this and are backing up this belief. We have trained a number of boys during the past four years, we have eight now in training and we also employ a number who are out of their time. I shall refer to this group a little later.

The Engineering Graduates

7. We have found another group very much worth while, namely, college graduates who have been selected to serve an apprenticeship of two and one-half years. Although not indentured, they do serve under an agreement which we have made with them.

8. One of this group is now assistant superintendent of our steel foundry. Another recently resigned, after being in our employ for six years, to accept a position as superintendent of a steel foundry. Still another is chief melter in a foundry producing electric steel castings in another branch of the company.

Indentured Apprentices

9. Coming back to the regulation indentured apprentice course, our company, as most of you know, has maintained in

our various works very extensive courses and has graduated many hundreds of boys, most of whom were in the mechanical and pattern-making trades. Our Mr. Mellen went into detail in this connection last year in his very fine paper[1] on the subject. If I may be pardoned, I am going to take the liberty to present again a few of the high spots, in order that you may fully realize what apprentice training has meant to our Lynn works since 1902.

10. We graduated during this period 1167 apprentices, 50 per cent of whom still are with the company. From these graduates we have developed three managers, 28 engineers, eight superintendents, eight supervisors in industrial training, 40 graduates teaching in public schools and colleges throughout the country, and our manufacturing plants are absorbing the apprentices as fast as they graduate. At present there are 200 boys in training at Lynn.

Experience with Foundry Apprentices

11. Now we come to the foundry apprentice. Many years ago we made a half-hearted attempt to train boys. A few graduated. The first one to graduate went West shortly after and later became interested in the foundry business and has since done remarkably well financially. For many years thereafter interest waned, but as previously stated, about four years ago—when the importance of training foundry apprentices was stressed so much—we started a group of 12 boys in our gray-iron foundry at Lynn under the leadership of a good molder.

12. Of the graduates from this group, one is acting as assistant foreman of main floor molding and another is on time-study work, while three others are doing some of our very best work on the molding floor. Another left the course after two years, went to a foundry trade school, returned to us after graduation and is now assistant foreman in our light gray-iron foundry, and is doing an excellent job.

13. We have been so well pleased with the character of the boys who graduated that we transferred a graduate apprentice from one of our other plants and employed still another from a well-known local foundry when our own graduates did not fill our needs. Both have done some very valuable time-study work.

[1]Mellen, M. H., *Foremen's Conferences at the River Works, General Electric Co.* TRANS. American Foundrymen's Assoc., Vol. 37, pp. 533-538 (1929).

One now is acting as assistant foreman in the gray-iron foundry and the other is still engaged on regular time-study work in our steel foundry.

Training Need Greater Than Ever

14. We sometimes hear men of intelligence ask the question, "Why train apprentices today in the foundry when machine methods destroy the opportunity to absorb the graduates?" My answer is that if we ever needed men of mechanical ability and practical training in the foundry, we need them now.

15. Competition was never keener than at the present time. New processes are making inroads into the foundry industry and call for keen, intelligent men to raise the standards of the foundry in every particular and place it in its proper place in the manufacturing group.

16. After all, in our basic industry the manufacturing cycle usually begins with castings. If we can, by using intelligent methods, produce a product which is superior to that which was in times past the source of so much trouble and economic loss, we shall at least have made our contribution to the progress of the age.

(Discussion of the preceding paper is combined with the committee report on Apprentice Training, and will be found on page 774.)

Report of the A. F. A. Committee on Apprentice Training

To the Members of the American Foundrymen's Association:

While there is no way to measure the interest of foundrymen in apprentice training, it is the opinion of the Committee on Apprentice Training that this interest has increased during recent years in distinct contrast to the almost complete indifference which existed some years ago. No great energy has been displayed in the industry in actually engaging young men for training, but at least it can be said that considerable curiosity regarding apprenticeship and its methods and results has been aroused.

Evidence of this changed attitude is the greater attendance at apprenticeship sessions and more considerable correspondence carried on by committee members and others regarding apprenticeship in the foundry industry.

The most outstanding evidence, however, is the foundation of a number of foundry apprentice schools in foundry districts. An outstanding example is the very fine school which has been built in Cleveland within the past year, and which is now functioning. Also, Connecticut foundrymen contemplate a similar institution.

Educational Campaign

Because of the conditions existing in the foundry industry, the committee has felt that its efforts should be concentrated very largely on an attempt to stimulate still greater interest in apprenticeship, rather than to devote any considerable effort to the pointing out of the technique and procedure of apprentice training. The reason for this is that when an employer becomes very thoroughly interested in apprentice training, he can usually find ways and means of carrying out his plans without great difficulty.

In order to develop this interest in the industry, members of the committee have carried on a personal correspondence with foundrymen in their respective localities who have indicated interest in the apprenticeship movement in their response to a survey which was conducted last year.

Moreover, material on apprenticeship has been supplied for Transactions and Bulletin, the new publication of the American Foundrymen's Association. This consists of actual information, which has been made as graphic and interesting as possible, regarding apprentice training in the foundry industry, and a series of progressive letters prepared for publication by the committee and by prominent industrialists of the country.

ANALYSIS OF JUVENILE EMPLOYMENT LAWS

This year there has been made available to the members of the American Foundrymen's Association, an analysis of juvenile employment laws in the various states of the country. This analysis was made by a member of the committee thoroughly qualified for the work.

It is frequently alleged by foundrymen that the laws of the state in which they live practically prohibit apprenticeship or make it so difficult that it is impossible.

This analysis of laws was published in the January, 1930, issue of the A. F. A. TRANSACTIONS AND BULLETIN, and is so arranged that foundrymen may see at a glance what laws are enforced in their respective states regarding juvenile employment. The reason for making this analysis was the conviction of the members of the committee that these fears of foundry operators were very much exaggerated in most cases.

APPRENTICESHIP BOOKLET

While the committee is primarily interested in the promotion of interest in apprenticeship, it has not completely overlooked other phases of its work.

In conjunction with the Industrial Education Committee of the National Founders' Association, it is preparing a booklet outlining the standards of foundry apprenticeship which have been generally accepted, including requirements and suggestions for procedure in the establishment and maintenance of foundry apprenticeship. This work has been under way for about a year, and the booklet should be published within a short while.

APPRENTICESHIP SESSION

The apprenticeship session for this convention was planned after a careful study of suggestions made by those who were in attendance at the session last year. Their names were secured and letters were afterward written requesting them to write to the committee how, in their opinion, the apprenticeship session could be made more effective this year.

Of course, not all these ideas could be carried out as a number of them were directly at odds with each other. However, the nature of the session and the subjects covered are in direct compliance with suggestions received from the majority of those who were in attendance last year.

Accordingly, the apprenticeship session is not to be devoted to an intense discussion of complicated problems of technique in foundry apprentice training, which would be interesting only to those who have been active in the work for some time, but is of a more general and instructive nature.

One paper points out the benefits of apprentice training as a means of preparing young men for positions of responsibility in the foundry industry, and the results which have been secured in this direction.

The other paper is of more general character and points out the need for greater attention on the part of foundrymen to their personnel and training problems, and the difficulties which have arisen from neglect of these matters.

APPRENTICE CONTEST

The committee has again sponsored contests for apprentices in iron and steel molding and in pattern making. These contests are held in compliance with regulations which have been published by the committee. Patterns and drawings for the contest are selected by the committee and are distributed to local foundry associations or individual foundries in which contests are to be held.

These local contests are in charge of local committees and boards of judges, from whom an affidavit is required that the regulations of the association have been fully complied with.

The castings and patterns which survive the local elimination contests are sent to the convention of the American Foundrymen's Association, where a final selection is made by a qualified board of judges. Castings are judged according to predetermined standards and are marked by number so that judges may not know by whom they are made.

The work submitted for these contests is intensely interesting, as it shows what young men under supervision may be expected to accomplish.

EXHIBIT

For the first time this year, conditions have made possible an extensive exhibit of apprentice work in addition to the contest specimens. This exhibit is in two divisions.

The first division includes a variety of foundry work which has been produced by the students of the new Cleveland Foundry Apprentice School. This exhibit has no connection with the contest held by the association and all the work was made by young men who have been students of foundry work for less than a year.

The second division includes a series of charts giving graphic and pertinent information regarding foundry apprenticeship problems, such as turnover, proportion of apprentices who finally graduate, the development of apprenticeship in various industrial districts, the proportion of apprentice graduates who remain in the trade, reasons for apprenticeship failures and other items.

APPRECIATION

The committee wishes to express its gratitude to the officers, directors and members of the American Foundrymen's Association for making available facilities for the work of the committee, and for their constant encouragement and support.

Respectfully submitted,

C. J. FREUND, *Chairman*,
Committee on Apprentice Training

DISCUSSION

ORAL DISCUSSION

CHAIRMAN D. M. AVEY:* The matter of training men, whether it be from the standpoint of apprenticeship or education of men probably destined by ability or inheritance or what you will for executive positions, strikes me as comparable to a conservation measure. It is a reforestation of manpower.

That this work has been and is being handled so well in the American Foundrymen's Association is a tribute to the men who have been giving their time and attention so strongly to the problem.

It is interesting to note, in this regard, that those who are heading this movement at present have been in the position of "after taking" themselves. In other words, a great many of them have been through the course, have been raised from "sprouts" in the "hothouse" of apprentice training. In consequence of this they have an attitude or type of mind which is receptive to the best ideas, which bears in mind the psychology or human element and, all in all, is most fortunate.

C. J. FREUND:† On behalf of the Committee on Apprentice Training, we feel that there has been a considerable increase in interest in apprenticeship in the industry. There is no way, of course, to measure this interest but we believe there has been certain evidence of such an increase.

The greatest single item to indicate that increase we feel has been a certain curiosity regarding apprenticeship in the industry. The committee has had to handle more correspondence; people are asking more questions. There is a greater request for booklets regarding apprenticeship, and preprints of papers on the subject were in good demand.

Another very tangible evidence of this increased interest is the establishment of foundry apprentice schools in different parts of the country. An outstanding example is the foundry school which has been established in Cleveland by the board of education and the industries co-operating. The Connecticut foundrymen also have contemplated starting a school, and the East Bay Foundrymen's Association as well are contemplating building a school within the next year.

The committee has felt that its effort should be concentrated very largely on an attempt to stimulate in the industry a greater interest in apprenticeship rather than to try to go out and do anything in the way of actual organizing. In order to stimulate this interest, the committee has corresponded with foundrymen in various districts who have indicated a desire for more information. While I do not believe any of them have set up apprentice programs as a result of this correspondence, at least more and more people are hearing about it.

The apprenticeship session at this convention is the result of a very careful survey of the requirements. We corresponded with every person who attended the 1929 session and our program is based very largely upon the returns from that correspondence, giving due weight, of course, to the opinions of those who probably would be better qualified to speak.

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*Penton Publishing Co., Cleveland.
†The Falk Corporation, Milwaukee.

E. H. BALLARD: The thought occurred to me quite a while ago that our personnel was lacking in the matter of having technical men in the foundry. My first contact with that particular type of young man was with a student from Massachusetts Institute of Technology who wished me to give him a subject for his thesis.

(At this point Mr. Ballard gave explanation of the method by which this type of man became interested in and finally attached to the General Electric organization in a student capacity, later assuming executive positions.)

As I talk with the superintendents of our machine shops, I find they are looking forward to the time when they will have a bright boy graduate out of the mechanical courses. At present there are 200 boys in training at Lynn. Data recently published by our statistician covering the 28 years during which the company has been training apprentices in the various works of our organization, indicate that 4,000 have graduated, 2,500 still are in our employ and many are holding important supervisory positions.

It may also be interesting to know that there are 2,000 apprentices in the whole General Electric Co. at present. There are 68,000 to 70,000 employees in the eight to ten works, and 2,000 boys were enrolled this last educational year ending July 1, 1929.

S. M. BRAH:* I wish to compliment Mr. Ballard on his forethought in defining the word "apprentice," and his wisdom in pointing out that we are all apprentices. Especially is this true in the foundry industry, where such rapid strides are being made daily in technique, metallurgy and management.

Mr. Ballard, providently and rightfully, placed first in his discussion his comments on training the older men. What right have we, as managers and supervisors, to expect the older worker to train and instruct young men and boys in the mysteries of the foundry art, when the reward is so remote, when they themselves have no opportunity to obtain ideas in return and when no provision has been made for their advancement?

Again, how can we expect to obtain high-grade apprentices when the men who are responsible for training these young men, these apprentices, are not themselves adequately equipped—when they themselves are not scientifically minded? The answer, obviously, is that we have no right to expect it and we cannot train adequately under such conditions as these.

From J. G. Pearce, director of the British Cast Iron Research Association, I learned that most of the training effort on the Continent and the British Isles at the present time is being expended in the direction of the older worker. In England they have felt that upon the improvement of the older worker depends the immediate improvement of the foundry industry.

It is admirable for us, as apprentice supervisors, educators and foundrymen, to place our confidence in deferred returns by training appren-

*Tri-City Manufacturers' Association, Moline, Ill.

tices, and our efforts should not decrease along this line. However, we should also carry the additional burden of training the older worker, for here may be a happy solution of meeting the deficiencies of an adequate training personnel.

Mr. Ballard speaks of training the engineering-college graduate. This has become more or less of an accepted program throughout the country, and little need be said beyond the fact that it has been carried on satisfactorily in most places.

The General Electric Co. and Mr. Ballard are to be congratulated upon their wonderful work in training skilled help for the industry. Those of us who are close to the training problems of industry will heartily agree with Mr. Ballard, that industry now has a greater need for mechanical training and technical training than it had at any previous time.

In closing, the author of the paper states that competition was never keener, that new processes are making inroads into the foundry industry and that these conditions call for keen, intelligent men to raise the standards of the foundry industry in every particular and place it in its proper place in the manufacturing group.

In what manner can this be done more quickly than by educating the adult worker? Perhaps the foundry industry has here the happy solution for the problem of training personnel for immediate improvement of the industry.

Mr. Ballard, is the General Electric Co. at this time carrying on any formal shop training or leisure classroom work for the adult worker? If so, would you go into details for us?

E. H. BALLARD: Of course, at our Lynn works we have a fairly large organization and school facilities, including a proper staff of teachers, and there is opportunity of the kind you mention all through the plant. It matters not what work a man may be doing; if he is desirous of taking up another branch of work, he can do so.

For instance, during the winter months, on the men's own time, they have classes in blueprint reading and in welding. If a mechanic wishes to learn to operate some other kind of machine than that with which he is familiar, he has the opportunity of taking up that work on his own time, under proper instruction. As students become proficient in this new work, their names are posted in the employment office under the proper tool-operator classification, and when the need arises for that type of man, they can be called upon to change to other work. The men are now availing themselves of this opportunity in a manner which is very promising.

We have found this one of the best means of educating our foundry foremen. When we start our class training for apprentices, in addition to the school work which they are obliged to take up in their course, we require every foreman in core making and molding, the cost man in the office, and all, to write a simple paper in plain language for instruction of the boys.

Each of these men has a session with the boys for discussion of the paper, and by their having to write a paper in their own language, free

from all technicalities, they must do a lot of studying. In other words, they find they have forgotten many things which they thought they had fully absorbed. We have found this has been an education in itself, as this policy produced quite a group of papers.

The opportunity for evening study is still there for anyone who wants to take the time. This applies not only to the trades but also to the office work as well—accounting, comptometry work, typewriting, etc. We have a number of typists and stenographers through the works who increase their efficiency by taking these after-hour courses on their own time, and we find that many are considerably better off than when they started. It has been a wonderful opportunity and has resulted in a great deal of good.

CHAIRMAN D. M. AVEY: This discussion is bringing out the three important lines of development in training, that is, the young man—the apprentice starting in to learn a trade; the older man who wants to improve his own technique, and the engineering student leaving school who really wants to get an education. I will not say "complete" an education, because we all know that no college student is educated when he leaves college, although he may think he is. The larger organizations, such as Mr. Ballard's, really conduct an institution of learning comparable with some of our great engineering schools.

F. A. LORENZ, JR.:* Mr. Ballard gives us some very interesting data on the results of an apprentice-training program. It probably should be borne in mind that the General Electric Co. has many allied lines and that they have not confined their training entirely to the foundries which they operate.

With the American Steel Foundries, it has been entirely different. We are in the foundry industry exclusively. A number of years ago—at least twenty—the American Steel Foundries instituted a program for training the college graduate.

Our organization being practically the leader at that time in this type of foundry training, we soon found that we were running a sort of benevolent institution, in that we were training foundry foremen for all of our competitors, and that the number of men retained in our own organization was less than 10 per cent. This shows the other end of the retention field when it applies to a foundry insofar as apprentices are concerned.

Gradually this program has evolved itself to a point where we retain and educate only a very few men from the technical schools. We pick them very carefully and we do so with the idea that we can train them and offer them, on graduation, a definite opening in our company. Most of the men whom we have retained are filling very responsible positions with our company—assistant works managers, sales agents, managers of departments, etc.

However, taking it as a whole, we have trained a great many more men for other people than we have for ourselves. That is probably a

*American Steel Foundries, Chicago.

slightly selfish point of view and it probably is one of the penalties that the American Steel Foundries has paid for being pioneers in the field of taking graduate engineers as apprentices and training them to become efficient workers.

We have had foremen training—opportunities for the education of our foremen—carried on by the works themselves and also by outside people such as the Business Training Corporation. At the present time, at our Granite City Works at Granite City, Ill., we are carrying on a foundry apprentice-training program which has been very successful. At our Indiana Harbor Works at East Chicago, Ind., we are part of the community program, which not only trains foundry apprentices but apprentices for other industries as well.

However, the results to us, of training the foundry apprentices to become journeymen, have been far better than through the old-type program. Our turnover at Indiana Harbor has been absolutely nothing in two years. At our Granite City Works our turnover has been very small.

There may be a number of executives who are contemplating a training program for their industries. For their benefit, we do not think there is any one program or any one type of program that will fit every plant. We have not found that one type of program would fit all the plants of the American Steel Foundries.

It is not a thing that can be picked up in a cut-and-dried manner and given to a plant. Each plant will have to consider its own problems and work out a program, possibly taking the best from other programs which have proved successful.

The one most important point which must be borne in mind is this: No one foreman, or no one apprentice supervisor, or no one supervisor of an educational institution, will ever put over an apprentice program unless it first is approved and desired by the supervisory personnel of the plant.

It will be an utter failure if some executive simply says: "Here, now, you had better put in an apprentice program," with the foremen not in full sympathy with the entire proposition. At best, it is a difficult proposition to put through, as any one of our managers will tell you, and it has to be followed very carefully and very wisely, and the interest of the apprentices has to be maintained.

Mr. Ballard touched upon their program, which requires their foremen to give papers before the apprentices. This type of educational work is going on at both our Granite City and our Indiana Harbor plants.

At Indiana Harbor the apprentices have organized a club and have two meetings a month. At one meeting, through the Apprentice Program Committee, the job of presenting a paper is assigned to one of the apprentices; at the second meeting the foreman or department head presents a paper to the apprentices.

We have found exactly what Mr. Ballard found: When the foreman or the superintendent was required to get up in front of ten or twelve apprentice boys and talk on his subject, he found that he had to do considerable digging and brushing up on his subject to be able to present

it in an understandable way to the apprentices. It has had a very beneficial effect on our whole supervisory force. The reaction is that they have found out that teaching apprentices in their departments is a much larger job than they supposed it would be, and the results, on the whole, have been very beneficial.

F. K. FERGUSON:* In East Chicago we have a program that necessitates cooperation between the schools and the industries. We believe that this type of program can be worked out very beneficially to both parties. In the first place, it will be found that the schools are quite willing to cooperate in any sort of training program if only they are approached on the subject.

In East Chicago, this year in particular, the vocational director there, Mr. Bell, has been having group meetings of the men from the industries and the teachers in the vocational department, trying to find out what industry expects of the product of the school shops. These meetings are breaking down some of the barriers that have existed between school and industry, and each is beginning to appreciate the other's point of view.

When our apprentice program was begun two years ago, it was decided to hook up the schools and industries in this training program and I was selected to supervise the job. I presume that the set-up is similar to that in other parts of the country, the boy signing a four-year agreement and going to school half a day a week on the employer's time for about 11 months in the year. During this school time he studies subjects that will be of special benefit to him later on. We try to correlate his school work and his job as closely as possible.

Mr. Lorenz made a statement which I am finding true in almost every plant into which I go—there is a kind of upgrading in the personnel of the plant, of the men who have charge of the boys, particularly the foremen. The boys keep them on their toes—make them know what they are talking about.

Just the other day I was in one of the plants and a foreman said to me: "I think one of the things that stands out in this program is the fact that we fellows in the plant have to watch our step. These boys are continually asking questions, and sometimes we have to look up the answers."

Another angle to this, an angle that I am particularly interested in, is the matter of selection. I am particularly interested in the question of guidance. Consider these boys from the junior and senior high-school years—boys who have no definite plans, possibly, as to the vocation they expect to follow.

What are we going to do with them? They come to me and say: "I am interested in your apprenticeship scheme and I would like to learn a trade."

I say, "What trade are you interested in?"

The answer, many times, is: "Oh, I don't know. What have you open?"

*East Chicago Public Schools, East Chicago, Ind.

To me, that is tragic. A boy is ready for his life's work, ready to start in on the thing that he probably will be doing all the rest of his years, and yet he does not know definitely what that thing is he wants to pursue.

I believe there should be some sort of guiding scheme in the schools that will help these boys find themselves, so that when they come to me, they will say: "I want to make patterns," or "I want to be a molder," or "I want to be an electrician." It would be a happy situation if we could arrive at that point, and the schools are starting to work in that direction already. Quite a little is being done in the matter of guidance in the high schools and colleges.

In the first year of our program, the apprentice turnover in some of our plants was rather high. Mr. Lorenz' plant was very fortunate—their turnover was zero. But if turnover is charged only after a probationary period, our turnover was not excessive.

We find that most of our turnover comes in the first few months. I am a firm believer in a probationary period. It is unjust to the boy coming in under the circumstances I have outlined—not knowing definitely what he wants to do—to sign him up on the day he enters the plant, for four years in some specific trade. That is unfair to the boy and to the employer. He may not have any special qualifications for foundry work—he may never have been in a foundry in his life.

Of course, before they are signed up, we take them through the foundry and let them see the molders at work, but that is a very superficial knowledge indeed. The boy should have a probationary period to see whether he has any aptitude for the trade he selects, and to see what he thinks of the men in the plant and what they think of him as a fellow workman.

Last year I conducted a survey in the two high schools of East Chicago to try to find out to what extent the boys in the senior year had come to a decision as to what they wanted to do when they left school. Many of our boys in the industrial district leave school as soon as the law will permit them.

In Indiana, according to the interpretation of our Workmen's Compensation Act, it is a bit dangerous to hire boys in some trades between the ages of 16 and 18. The compulsory attendance law permits them to leave school at 16 but will not let them go to work until they are 18. They have two years of job hunting and loafing, and they acquire some habits that make them not quite so desirable when they come to us for apprentice training.

As to the results of my survey, I did not find that one boy out of the 366 was interested in molding or core making, and only four were interested in pattern making. A large percentage of them said they were going to be engineers, doctors, lawyers, teachers, and a lot of professions that they probably never will enter. Statistics show that only a very small percentage of these boys will ever go to college and prepare for these professions which require an education higher than the secondary level.

Another interesting question on my questionnaire was this: "What

is the trade of your father?" I asked them if they were interested in making that trade their life's work. Only 20 boys wanted to enter the trade or profession of their fathers.

Then this question was asked: "Has your father ever advised you to follow his trade?" We found that about 60 per cent of the fathers had advised their boys not to do the thing they were doing, and only eight per cent indicated that their fathers wanted them to choose the parent's vocation.

That was quite interesting to me, because it indicates in a measure that in this great industrial democracy of ours, large numbers of people are not entirely satisfied with their life work. Nor do they care to have their sons follow in the fathers' footsteps.

CHAIRMAN D. M. AVEY: We can always depend on Mr. Lorenz to liven things up a bit by expressing a viewpoint that perhaps may be contrary, but which brings out the discussion we want. He raised the question as to whether it pays to train apprentices, since they all go elsewhere.

I cannot give Mr. Lorenz credit for originality in that thought. In fact, reading back through the old files of *The Foundry*—back to the early days of the American Foundrymen's Association (the second or third meeting, I believe)—the discussion was on apprenticeship, and this same idea was injected.

Our larger organizations have the facilities, the talent and the ability to do a great many things that perhaps some of our smaller units cannot do in a technical way. We owe a great deal to our larger organizations, such as the American Steel Foundries and the General Electric Co. for the improvements they have introduced in foundry practice.

But just for the sake of discussion, Mr. Lorenz, did you ever find any rebound? Did any men who had been trained in other organizations come to your own plant?

F. A. LORENZ, JR.: Taking it by and large, the accession of the American Steel Foundries of technically trained men for the foundry proper—that is, foundry executive, superintendents, etc.—from other apprentice courses, has been very small, and practically nothing in the way of technically trained college men in the foundry apprentice group. At the present moment, considering my twenty years of association with the Steel Foundries, the only men I can think of are possibly some of our chemists or metallurgists, and I am fairly sure that none of them ever took a foundry apprentice-training course after being graduated from a technical school.

I would like to ask that same question of four of our works managers. I wonder if they know anything about it.

C. D. CAREY:* I cannot think of any.

P. J. WARD:** I do not know of any.

L. C. FARQUHAR:† I cannot think of any at the present time.

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*American Steel Foundries, Verona, Pa.
**American Steel Foundries, East St. Louis, Ill.
†American Steel Foundries, East St. Louis, Ill.

H. M. RISHEL:* I can think of one. We have a Westinghouse man who is our chief engineer and who took training with the Westinghouse Electric & Mfg. Co. He is a recent acquisition—within the last few years.

CHAIRMAN D. M. AVEY: Was the American Steel Foundries conducting anything of that nature when all of you gentlemen became affiliated with that organization? Are you survivors, in other words?

F. A. LORENZ, JR.: We are survivors. I think our group—with the exception of Mr. Carey, who came with us through acquisition of another company—represents in the aggregate possibly 100 years of service. Thus we are old, dyed-in-the-wool foundrymen, if you want to classify us in that manner.

On this discussion, Mr. Rishel, the Works Manager of our Granite City works, is familiar with the work of the schools in that district, and there are some very interesting developments taking place in the Granite City district of which he can tell us.

H. M. RISHEL: Three years ago at the Granite City plant, realizing the great need for the training of men in our foundries who would be actual tradesmen rather than primarily foremen, we started a course that was, briefly, as follows: A course was subscribed for the men through a correspondence school, for which they gradually paid so much out of each pay check. In addition to this, one of our men who was primarily interested in the work followed it through. The boys were supposed to spend at least four hours in home study and four hours in the class room which we provided for them.

At first we thought we would have difficulty getting enough boys interested, and as a result we overloaded ourselves. I want to emphasize that, in starting an apprentice course, do not worry about not being able to get live-wire boys interested. We entered too many and they were not properly selected—there were too many in proportion to the size of our plant.

As a result of that experience we have had boys who were not especially fitted for the course, and we had some turnover. Since then we have decided that a boy must work in the plant practically six months, so that he has found out whether he likes the work and wants to go ahead with it, before he is put on the course with a definite idea of its purpose.

We now have applicants who are relatives of our own workmen and are awaiting a chance to get on the course. Our first two boys have been graduated and we were able to give them a job. That is one of the dangers of getting too many on the course—not having openings for them when they do come out.

Another danger of getting too many is that it becomes a burden to the department head if he has too many and must shift them around from one job to another. Certainly it is not fair to the men if they are not shifted on the jobs. For instance, in the machine shop, if an apprentice is put on a drill press and kept there for a period of months,

*American Steel Foundries, Granite City, Ill.

justice is not being done the boy. What he needs is an all-around training.

This course is giving us very splendid results, and it is more than paying us at present for the money and energy put into it. We thought it would be a matter of putting in money and getting it back at some future time, but to our surprise we feel that the thing has been of such benefit to the plant as to have paid its way from the very start of the plan.

At the time we started our course, there were no school facilities in our district similar to the one at East Chicago. However, about two years ago—six months after we started—the Community High School at Granite City began a vocational-training school, and it is now very well equipped.

The part that pleases me most about this school is the fact that they are trying to train tradesmen for the particular industries located at Granite City. The principal of the school, Professor Diemer, requires that his teachers get out during the summer and get an actual job in one of the plants, so that they will be in close touch with the actual needs and will know what is going on in the various plants of the district.

Then, so far as possible, the boys who are taking this school course are doing machine work or pattern work for orders that actually are used in the plants. For instance, the school authorities will come to us and say, "Have you some castings to be machined, or some patterns to be made, which we can take into our school shop and have these boys work on?" In this way they are hooking up their work directly with the industries located at Granite City.

After the boys have spent two years on their high school vocational-training course, there is an arrangement by which the boys are paired. One of the pair goes out into one of the plants and works for two weeks while his partner is in school; at the end of two weeks, the other boy goes out. We now have four of those boys working in our plant, and while it has not been in operation long enough to say much about it, the prospects are that it will work out very well.

A. D. LYNCH:* From the remarks of Mr. Ferguson and the gentlemen from the American Steel Foundries, I am led to believe that we have a cooperative training plan in our Ohio schools which is more helpful than the plan under which they work.

It is not necessary for us to have a training period in our high schools for prospective apprentices before entering into a contract. Boys who are interested in taking such training enter the vocational training department of the school at the beginning of their junior year in this school.

Machine shop and foundry equipment is provided in the school and related subjects are taught in the class room—mechanical drawing and sufficient mathematics to prepare the boy for any regular apprentice training course. During his senior year in high school, the boy spends one week in school and one week in some industrial plant of the city,

*Ohio Brass Co., Mansfield, Ohio.

thereby getting actual shop experience and affording the opportunity for a better acquaintance between the boy and plant executives and foremen.

As a result of this plan, by the time a boy graduates he generally knows whether he still wishes to follow a mechanical trade or not, and the plant where he has cooperated knows whether it wishes to accept him as an apprentice. At our plant we have apprentice training in pattern making, tool making and foundry practice, and we have found our Ohio vocational-training program in the schools a wonderful aid to our industries.

J. B. GREENSTREET:* In our plant at Philadelphia we also send our apprentices to school on Saturday morning. We have a Central High School Annex which includes a class in foundry subjects. These boys attend four hours every Saturday, except during July and August, I believe; they are paid by the company.

We also have lectures and talks. The foremen hold the meetings for the boys and sometimes I give a talk, while at other times someone else talks to them. Some of the questions they ask us are surprising. Very often it puts us on our toes, as they bring up subjects one would never think they had in their minds.

We start them off on three months' probation before we sign them up at all. We have them in the shop for three months just working around different places. We have a law in Pennsylvania forbidding boys to carry molten metal until they are 18. We take them in when they are 16 and try them in the core room and on the machine floors and bench floors, and when they are 18 we let them pour molten metal.

In the so-called Philadelphia district there are 8 steel foundries; 77 iron foundries; 46 brass foundries; a total of 131. The recent study on apprenticeship in this district elicited responses from 54 foundries, or 41 per cent of the total foundries in the district. This is an adequate number from which to draw conclusions which may be presumed to be reasonably accurate of the apprentice situation.

There were employed in these foundries at the time, 593 journeymen floor molders, 200 journeymen bench molders and 232 roll-over and squeezer operators. In addition, 260 journeymen male coremakers were on the payroll. This is a total of 1,285 skilled journeymen.

At the same time, there were 156 apprentices and 125 trainees, the latter being men who are working under instruction at some specialized branch of the trade, being advanced to more difficult work as they become qualified.

There are, therefore, 22 employees under instruction for every 100 skilled journeymen employed. In floor molding the percentage of those under instruction to journeymen is 18; in bench molding, it is 10; in machine operating, 28; in coremaking, 35.

Apparently the foundrymen in the Philadelphia district have finally realized the necessity of maintaining a skilled labor supply. It is too much to expect that the training in all the plants is as carefully laid out

*Olney Foundry Co., Philadelphia.

and supervised as one would like it to be, and there are too few learning bench molding and perhaps too many learning coremaking. That this is so, is evident from the scarcity of bench molders and the abundance of coremakers.

Nevertheless, if this ratio of apprentices and trainees to journeymen can be maintained, we may well feel that unless there is some very substantial increase in the foundry business in the district, our skilled labor supply will be adequate to meet our demand.

S. W. UTLEY:* In thinking of this question of apprenticeship, I am reminded of a story told me many years ago of a philosopher in an ancient state who was watching a procession one day. The first section of the procession consisted of a lot of elderly men who walked down the street, some of them with rather tottering footsteps, and who bore above them a banner which read: "We Have Been the Defenders of the State."

The philosopher looked at them with tears in his eyes and said, "You are a fine bunch of men, but you will soon pass on. What will become of the state then?"

They were followed by another section of men in the prime of life, who bore a banner reading: "We Are the Defenders of the State." As the philosopher looked at them he said, "Yes, but you will soon follow the first section, and what will become of the state then?"

But they were followed by a bunch of young fellows who did not keep their line very well and whose step was not the measured tread of marching soldiers, but who bore aloft this inscription: "We Will Be the Defenders of the State."

Then the philosopher turned away, and he said, "Now I am happy, for having seen this section, I feel sure that the safety of the state is assured."

That is the state, the oldest form of human organization, which long ago realized that the training of the young was necessary for its perpetuity. It is a policy which industry, the newest form of human organization, is just beginning to realize, to realize quite naturally—or, rather, quite naturally they are slow to realize it, because the birth of industry was the invention of the steam engine and the formation of the machines that came after it. Naturally, during the first 150 years, in the very youth of that type of society, they thought more of the machine that made it than of the men who ran the machine.

That is especially true in the foundry industry, because the pouring of metals is one of the oldest arts of the human race and, like any old art, it is a thing that has grown up on tradition. Our foundry practice, up to a short time ago, has largely consisted of doing those things which our fathers or the molders before us taught us to do, without very much inquiry as to whether or not, in the light of all our experience since, they were the best things to do.

Foundrymen will all agree with me that during the last ten years an entirely new picture has come into the foundry industry. Many of

*Detroit Steel Casting Co., Detroit.

our men are saying: "This industry is just rotten with tradition. The thing we must do is to examine it from a purely scientific standpoint, to assume that the thing we have always done is wrong and to see whether we cannot find some way that is better than the way we have been doing it."

In approaching from that standpoint, it is self evident that a big field lies before us for educating the young men in these new ideas which are just coming to us, rather than in the old ideas which have been traditional in our industry since its foundation.

Whenever a group of foundrymen get together, they usually talk about their various troubles—and we all know we have enough troubles. Some foundryman said the other day that he was sure he was going to Heaven, because the foundry industry was hell on earth and he was entitled to some reward after he got through with it.

One of the complaints is that the old type of boy has disappeared and that the modern fellow wants a white collar job—something easy, something that does not require very much effort. I wonder whether we in the foundry have not just assumed that, and whether we have not neglected to think that perhaps that attitude is somewhat our own fault and not entirely the fault of the boy.

I was interested in the remark that the boy who comes to the apprentice school often does not know what he wants to do. I wonder how many of us, even as we get on the other side of the Divide and reach a point where life is largely in the background, have yet found out what we want to do. Are we not expecting too much of the boy of 16 or 18 or 20 if, without any guidance and without any help on our part, we ask him to solve the problem which many men at 40, 50 and 60 have not yet been able to solve, with all their experience and their knowledge?

It is true that self-trained men have successfully operated old-fashioned foundries in the days gone by, but the very complexity of our modern equipment and the multiplicity of our requirements call for a training unknown in former times. While our fine modern equipment is of the greatest help to all of us in the foundry industry, it will not do away with the necessity for careful and intelligent training. After all is said and done, man still is superior to the machine. Man still controls the machine, not the machine the man, even in this mechanical age of ours.

I am very glad to acknowledge that many individual foundries and many organized communities have tackled this problem and are doing a very fine piece of work. I speak now of the smaller foundries and of the industry as a whole, when I say that we have not yet appreciated the importance of this problem of training someone to carry on, and to carry on in a more complicated way, after we have passed out of the picture.

There is another effect of this thing—the effect of training on those outside of the industry. If the situation is examined carefully, it will be realized that a good deal of the respect we have for people in other lines of work comes from the knowledge we have of the time it took them to prepare themselves for their work.

We know that the doctor, the lawyer, the professional man of every kind, has to go through a long period of training. We do not understand the complications of their professions, but we appreciate their worth because of our knowledge of the time it has taken them to acquire their skill.

Thus, with industry, we appreciate the value of an industry much more when we realize that mastery requires a definite, concentrated effort on the part of the man who is carrying it on. Much of our respect for our telephone companies, public service companies and railroads is due to the fact that we all realize they have an intensive, intelligent working system for training men who are to serve us through their organizations.

I was interested, at a Chamber of Commerce meeting in Washington a few weeks ago, to hear Homer Ferguson, president of the Newport News Shipbuilding Co., tell something of their apprenticeship problem. He said that when they established their plant—and no plant in the world requires so many skilled trades in the production of its output as does a shipbuilding plant—they had to go to Philadelphia and other places to get practically all their skilled help—and skilled help was what they needed most.

A few years ago they embarked on an intensive, intelligent, thoroughly conducted plan of apprenticeship training, not only for the foundry but for all the trades in their big industry. Mr. Ferguson said that today they are absolutely independent of any outside source; that the Newport News Shipbuilding Co. is manned, so far as new personnel is required, entirely from their trade or from their apprentice-training schools.

Not only that, but on the occasion of a new plant coming to Newport News recently, they offered and agreed to let the new plant have sufficient men—about 400—from their organization to start that plant and get it running, provided only that the plant would agree to cooperate with them in the training of apprentices to take up their own work and the work of the shipbuilding company.

Youth, because of some intuition or something else, often realizes much more clearly than do we who are older, that conditions have changed and that they must face new problems in a new way, and they realize it much more readily. We are apt to live in the generation of our youth. They are living their youth in the generation of the present day.

Unless we get to their level and realize that if they are to come into the foundry, they must come on a trained basis rather than on the basis prevalent in our day, we cannot expect that we shall get the interest or the help of these young men who are looking to the future, while many times we are looking into the past.

If it happens that setting up an apprentice training department proves profitable from the start, as it has in many cases, then the company is so much to the good. However, the criterion of the success of that department must not be established for the first two years, nor whether it pays on the ledger sheet, but rather whether it is accomplish-

ing its real objective—to train men who will be successful foundrymen and successful members of society as a whole.

G. P. SINGER:* As I listened to the speakers, a question came to my mind—a question that has been shot at me more than once: "What does it cost to train apprentices?"

Unfortunately, I have not been able to answer that question as to what it costs to train an apprentice. Possibly one of the reasons why I have not been able to do so is because I have never looked at it in the light of dollars and cents, but rather as a vital necessity to the life of the industry generally and to the benefit of citizenship as a whole.

C. J. FREUND: Of course, as Mr. Utley pointed out, apprentice training should not really be a matter of dollars and cents. The important item in apprenticeship, obviously, is the contribution which the manufacturer makes to the well-being of the industry and of society in a broad, broad way.

On the other hand, every department of a plant must be made to pay. In answer to the question, therefore, I can say—at least from our own experience—that apprenticeship does pay. It can be made to pay, and I am not merely saying that, nor guessing at it—we know this to be true.

Two years ago at the plant with which I am connected we made an actual analysis, an actual cost survey, to see whether apprenticeship paid us or not. This is the way we did it: We have the familiar job card for cost keeping. For every job or piece of work made in the plant, a card is punched which shows the elapsed time on the job, and then the time is figured out in terms of wages, the overhead items are added and from the card we then have a record of the actual cost in total shop cost, manufacturing cost, of that particular piece, less direct material used.

We got out all the cost cards for the entire plant for one year—there was a big pile of them. All our apprentices have clock numbers of 9,500. We pulled out from this pile all the 9,500 job cards, and that pile then represented complete information regarding the cost of all the work done by all apprentices in all departments during that entire year in the entire plant.

We next divided the apprentice cards by departments—foundry, machine shop, etc.—and arranged them again within departments according to the numerical order of the jobs. The jobs, the patterns, etc., of course, were all numbered. Then we went to work and arranged all the mechanics' cards, all the journeymen cards, in order of departments and job numbers. That was a tremendous job—it took three clerks eight months to do the work.

After that we took from the pile of mechanics' cost cards every card which indicated that a mechanic and an apprentice had made the same job at any time during the year. This was easy, as we had the cards in numerical order of job numbers, both on the apprentice side

*Reading Steel Castings Co., Reading, Pa.

and on the journeyman side. We made on the apprentice side a grand total of all costs represented by all those cards which were included in the comparison, and on the journeymen's side made a grand total of all the journeymen costs.

The grand total showed that the apprentices, in actual cost of the work done, including overhead, had a very distinct advantage, regardless of the slow time that they made, especially on machines with a high hourly machine rate. We found this was true in the various departments, and not only in the grand total.

Our comptroller then came along and said: "Let us be very conservative. Your burden charge on each one of these jobs includes a very small percentage, it is true, for the administration of apprenticeship, school attendance, supervision, etc., but it is a considerable item. It is now distributed over all the jobs—over the mechanics' jobs and apprentice jobs—as a part of overhead.

"Let us take our total cost of apprenticeship administration, school attendance, supplies and everything, and add it on the apprenticeship cards. We will be charging it twice, because it has been added once as a part of the general overhead and we will be adding it again specifically on the boys, but let us see what this leads to."

We did that and were still a safe margin to the good on the apprentice side. Thus, we know absolutely, at least in that year, that our apprentices cost us no money; and I imagine, because conditions have not changed much, that it can be said of every year that the same conclusion is true.

G. E. BERGSTROM:* Several valuable charts have been prepared by Walter F. Simon, Supervisor of Apprenticeship for the Industrial Commission of Wisconsin, and a member of the A. F. A. Committee on Apprentice Training. In taking up the various factors explaining why employers do not more generally adopt some plan of systematic apprentice training, it must be borne in mind that these charts are based on the findings of investigations in Wisconsin. The actual percentage figures are on file in the office of the Industrial Commission of that state.

Under one chart heading "*Why Many Employers Fail to Adopt Systematic Apprenticeship,*" comes "Lack of Leadership." As the chart is based on Wisconsin studies, we will concentrate on Milwaukee for purposes of study.

The prime reason why apprenticeship has been so successful in that city is that there has been leadership and cooperation on the part of executives of the different concerns in Milwaukee. They have cooperated, they have talked apprentice training, they have practiced it, they have lived with it and slept with it. The result is they have the active cooperation of everyone.

Practically every plant in Milwaukee is training apprentices; that is why Milwaukee has been so successful in promoting apprenticeship. In Chicago, on the other hand, one of the main reasons apprenticeship

*288 Blackhawk Road, Riverside, Ill.

has not been so successful there is that there has been a lack of complete cooperation.

The next reason why so many employers do not adopt some plan of systematic apprenticeship is that the "Value of Organized Training Is Not Appreciated." Mr. Ballard's paper brought that out clearly. If we would formulate a real apprenticeship course covering a period of four years, we would derive great benefit, far greater than we are deriving at present.

Another reason listed on the chart is, "Employers Are Not Organized or Agreed on a Program." No comment at all is necessary on that point. It is admitted as a self-evident fact.

Now we come to "Unwillingness to Assume Responsibility toward Learners." Many concerns, without hesitancy, will enter into a contract involving thousands of dollars as a strictly business proposition, but will hang back and temporize when it comes to the human element. They do not feel they can afford to tie themselves down to a positive contract to train apprentices.

"Fear of Giving Learners or Competitors Something for Nothing" is given as a reason why systematic apprentice training is not adopted by more employers. That fact was brought out very clearly and forcefully by Mr. Lorenz in his comments on the work of the American Steel Foundries.

Limiting ourselves to the consideration of the effect of apprentices going from one shop to another, it is a fact that if everyone contributes by the training of only one or two apprentices, each will benefit to some degree and the industry as a whole will benefit greatly. Skilled mechanics drift from shop to shop and it is regarded as the natural thing. It is a give-and-take proposition. The same thought should apply to apprentices.

Instead of one plant doing all the training and so becoming a Santa Claus to the entire industry and giving their competitors the benefit of their efforts, if each one would do his share there would be built up a feeling of understanding from which all would reap a substantial and valuable benefit.

A plant cannot expect to retain in its employ for all time every apprentice it trains. It does not expect to do that in regard to its skilled mechanics, and it should not expect to in regard to apprentices. It is natural for a young man, after spending the years necessary to learn his trade, to have a curiosity in regard to other shops. The chances are that, after he has had this outside experience, he will return to his home shop a broader mechanic and a more satisfied employee.

A most important reason is given next: "Indifference toward Future of the Industry." The discussion this morning disclosed the belief on the part of some that the foundry business is headed for destruction anyway, so what is the use of doing anything? That is simply human nature.

A lawyer tells his son "Don't follow the legal profession. Stay out of it." All that attitude means is that too close acquaintance with the difficulties and discouragements of one's business or profession so emphasizes their importance that one is blind both to the advantages and to the disadvantages connected with every other business or profession or occupation.

That attitude is unworthy of foundrymen, and most surely is not characteristic of the leaders of the industry. Nevertheless, it is a disturbing factor and must be recognized.

"Importance of Human Element in Industry Not Appreciated." That point should receive careful consideration. It is only too true, not only in the foundry but in the machine shop and in all other lines. It is not a defect of our own industry alone.

Industry, of course, has to regard the material standpoint, but in confining attention solely to the material standpoint to the exclusion of the human element, is there not danger of industry defeating itself? More attention surely should be paid to the men themselves. We must not lose sight of the fundamental importance of "the man behind the gun."

Then there is the vitally important question, *"Why Some Apprentice Training Programs Fail."* Under this particular heading is given the reason: "Proper Application of Apprenticeship Principles Not Understood." Mr. Lorenz brought that point out very clearly. As he said, unless the entire organization is sold on the idea, no apprentice training program is going to succeed.

No one set program can be adopted by all shops. A program must be flexible enough to be adapted to the conditions in each shop, which is another fact emphasized by Mr. Lorenz.

In case it is proposed to introduce a course of apprentice training, the first thing to do is to make an intensive study of all the conditions. Apprentice training must be profitable for the employer as well as for the apprentice. As Mr. Freund has pointed out, if the plan is properly adapted to the plant, it can be made profitable from a dollars and cents standpoint. If it is not, it becomes a fad or a luxury, to be cut off at the first sign of business depression.

It goes without saying that when it is the intention to introduce apprentice training, the first step is to sell the supervisor and keep him sold. His confidence must be won and he must be convinced that his suggestions are actually wanted. He is in a position to make suggestions because he is on the job, understands plant conditions, the attitude of the men, and the traditions and customs of the business. After he has been sold on the idea and sees its merits, he will become interested in following the program through, because he will see that it is of advantage to the shop.

Here is another factor that contributes to the failure of an otherwise good plan: "Poor Selection of Learners." Mr. Ferguson has commented on that point, with force. Last year Mr. Cornell presented a

paper on the same matter, but it is of such importance that it may be brought up again with advantage.

In Chicago there was no trade school where a boy could be tried out in various departments until it was discovered just what he was best fitted for. Here is the way it usually worked: A boy would come into the office and say, "I would like to learn the foundry trade," or "I would like to learn the machine-shop trade."

Too much stress cannot be placed on the importance of sifting that sentiment. What gave the boy that inclination—was it fundamental, or a mere passing fancy? It was pointed out by Mr. Cornell that at least five interviews were required before a final selection was made. The idea was to ascertain with absolute certainty whether or not the boy's mind was set on the particular line of work he mentioned.

The only way to determine that question is by a thorough "self-analysis." Nothing will take the place of that. The interviewer plays a very important part in the boy's future life, and every interviewer, right from the bottom of his heart, should think constantly of the boy and the boy's future during the interview.

If the boy is started right, he will develop into a real man, an asset to his company and, just as truly, to his community and his country. On the other hand, if he is persuaded to take up a trade he is not fitted for, or one that is distasteful to him, his life is doomed to failure and he becomes one of the chronic disturbers of business and social life.

Here is how the first interview usually goes: The interviewer will say to the boy, "Well, how did you like mathematics?"

"Fine!" the boy will reply.

"How did you like mechanical drawing?"

"Fine!"

"Have you ever operated a lathe?"

"Oh, yes."

"Well, did you get the 'feel' of it? Did you like it?"

"Oh, sure, sure."

"Did you like the smell of the oil?"

"Sure," was again the answer. He liked everything.

The boy would be told to think the proposition over and come back in about three days. On his return, another interview would be given him, and—here is the important point—it is at the second or third interview that the confidence of the boy is gained. The interviewer is then in a position to say: "Now see here, son, I have your interest at heart and if you will just be fair with yourself, I can be fair with you."

The next step would be to take a sheet of paper on which had been noted an analysis of both the boy and the job he aspired to, carefully noting the progress the boy had made in school in the various subjects related to the trade for which the boy expressed a preference. In my own experience, this method proved about 90 per cent successful.

With this sheet before him, the interviewer would say, "Now as

to mathematics, how well did you actually like that subject?" At the second or third interview the boy would say: "Well, it was all right, I got through." Then he would be tackled on mechanical drawing by some such question as this: "How did you like mechanical drawing?" "Well, pretty good. I knew what the dotted line meant and what the solid line meant."

So the interview would go right down the line. You will note that instead of the reiterated reply, "Fine," differences were beginning to appear and the boy's real attitude toward the subjects was beginning to appear.

From my own experience, it is fair to say that probably 15 boys had to be interviewed before one appeared who convinced me that he would come into the shop and make a success of his apprenticeship. That incident is mentioned because it is right at this point that so many programs fail—not enough attention is paid to selecting the right boy at the start. Nothing discourages an employer like an unusually high apprentice turnover. Our apprentice turnover was very small, and this was due to the careful selection.

The only way to look at an apprenticeship program is this: If one can not be fair and square with the boy and treat every boy who comes into the plant as one would want his own son treated, stay out of the apprentice-training field. There must be strict honesty about the whole thing.

Apprentice training must be a benefit to industry and to all mankind. Every one should feel that way about apprenticeship. Let us be honest and sincere about the whole thing and give our utmost attention to the selection of the boy for the work he wishes to do. The time and effort spent at the outset will be more than offset by the time and effort saved later on.

Now we come to the topic, "Poor Supervision—Irregular Advancement of Learners." That part of supervision is of outstanding importance. Some concerns start out on an apprentice-training course and do not take the supervisor into their confidence.

Of course, under those conditions, the superintendents and foremen will say, "Oh, these damn apprentices!" and neglect them all they can. They feel they are being turned into school teachers when they are hired for production. The apprentices are too much bother and they feel it costs too much to look after them as well as interfering with their routine jobs.

It must be stressed again and again that the person in charge of the apprenticeship program must gain the confidence of the supervisors, superintendents and foremen, and keep them sold on the worth of apprentice training. If they are once sold on the idea, it will be much easier to keep them sold.

Here is another important point: "Selfishness—More Production Expected Than Is Commensurate with Wages Paid." It is deplorable, but nevertheless a fact, that occasionally a concern or its foremen have the idea that, by getting a lot of apprentices, they are getting cheap

labor. That is not the way to regard the matter. However, if the supervisors are started off with the right idea, the "cheap labor" fallacy will not appear.

These three heads may be grouped: "Department Heads Not in Sympathy with Program," "Unfavorable Working Conditions," and "Unfair Adjustment of Complaints and Disputes." Of course, a boy while learning his trade will get into difficulties of one sort and another. When he does, do not be too hard on him. Give him a word of encouragement now and then.

Apply it to yourselves—suppose, when you are discouraged and things seem to be going all wrong, your boss comes in and gives you a word of encouragement. You know how it brightens things up and instills new energy into you. It is the same with the boy. The routine of the shop, the hours of application, are all new to him, and for a time it gets on his nerves. When you see a boy downcast, then is the time to speak a pleasant word.

Then we come to this final heading: "Promises Unfulfilled." Perhaps you think there should be no occasion to make such a heading. Unfortunately, there is. Sometimes it is not wholly the fault of the management. The boy or his parents may have put a broader interpretation on a promise than they were justified in doing, resulting in a mutual misunderstanding.

That is why I am stressing the need for strict honesty. Do not make a lot of vague promises that cannot possibly be kept. It is better to understate than to create false hopes in the boy. Always keep in a position to do a little better than the boy expects and he will reciprocate by doing more than you expect.

When it is all summed up, if properly organized, thoroughly systematized and if every one in the organization who is to have anything to do with the training of apprentices is thoroughly sold on the proposition, it will be found that both the employer and the apprentice, even looking at it from a dollars and cents point of view, will reap a decided benefit together.

S. GRANT CONNER:* I am connected with the Ohio State Board of Vocational Education in the special field of apprenticeship work. The Ohio State Board has put in the field four men whose services are available to industry in organizing training programs directly in industry. It provides the leadership and the assistance in working out the details of the apprentice training program which the plant managers and plant executives very often do not have time to give.

We would be very glad to send anyone information concerning this program and to be of service in any way. The board provides for service in the organizing, setting up and operation of the training program. It also provides, from state and federal moneys under the Smith-Hughes Law, reimbursement on the cost of instruction.

For instance, if you have a man in your factory who is assigned as

*Ohio State Board for Vocational Education, University of Akron, Akron, Ohio.

apprentice instructor—say, he is giving all his time to that job—the state department, out of state and federal funds, will reimburse the industry through the public schools for 50 per cent of that man's salary. In addition to the financial reimbursement, the continuous supervision of the state department representatives is available.

C. K. FANKHAUSER:* I wish to describe very briefly how our Cleveland training plan was put in operation, and I would like to ask M. D. Jones, who is principal of the Cleveland Trade School, to explain how the school itself operates.

About five or six years ago the Foundry Group of the American Plan Association of Cleveland began a study of apprentice training in the foundries. We had had apprentice training in Cleveland in individual foundries for a good many years, but some of the smaller foundries felt that they could not afford to maintain apprentice training plans, or found that they did not have the facilities for such training as the industry required.

Therefore, the Foundry Group appointed a committee to make a survey of the industry and evolve a plan for training apprentices for the entire industry, to eliminate "having one plant act as Santa Claus for the rest," and to distribute more evenly the cost of apprentice training. This committee finally came to the conclusion that if the cooperation of the Cleveland Trade School could be obtained and a centralized place for apprentice training could thus be established, the cost would be distributed more evenly throughout the industry and the training would be based on uniform standards.

After some four or five years spent by this committee in a thorough analysis of the problem, the Board of Education finally agreed to build an addition to the Cleveland Trade School. As a result, last year the Board erected a $50,000 building, with the understanding that the foundry industry of Cleveland would equip it with all of the necessary shop machinery.

The Foundry Group raised some money for an equipment fund and the equipment manufacturers contributed a great deal of machinery, with the result that the school was ready for operation last summer and contained equipment valued at $15,000. It is a thoroughly practical, up-to-date foundry, equipped for gray iron, brass and aluminum molding. The school also has a pattern shop.

This school was put in operation last September with an initial class of 25 boys. It operates on a four-year plan, cooperating with industry, under a plan that enables the boy to earn while he learns the trade he intends to follow.

The idea of the foundrymen of Cleveland in establishing this school was two-fold: First, to provide an adequate supply of properly trained skilled molders and coremakers for the entire industry of Cleveland—not for any particular foundry and not necessarily for the foundries that backed the school; second, to go a little farther and to train these boys so broadly and thoroughly in the industry that some of them will be

*American Plan Association, Cleveland.

able to go ahead and become foremen, superintendents and plant executives.

As an example of how broad this training is, I would like to mention the fact that the foundry school also has a pattern shop. The apprentices in the foundry receive a certain amount of pattern-making instruction so that they can understand the basic problems and troubles of pattern making.

The Pattern Manufacturers' Group of our Association now has plans under way to start a class for apprentice pattern makers beginning the first of July. This class will be set up in the pattern-making department of the present foundry school. This will enable the apprentice pattern makers to follow their patterns into the foundry where they will see them actually used in making molds. If a pattern is wrong, the apprentice can be shown exactly what is wrong with his pattern right on the job.

Thus, the two industries cooperating will give the apprentices in both trades a much broader knowledge of their trade.

M. D. JONES:* The main idea in the operation of the Cleveland Trade School is, of course, the functioning with industry. We are only operating ten trades. That is because we have had demands from only ten trades, and ten trades is large enough to support a program of apprentice training.

We have had most unusual support from the foundrymen of Cleveland. They have furnished the equipment for the school—all of the equipment, and much of the material as well. They also have given us active support—for instance, during the Christmas holidays—in finding a place for all of the boys in foundry work, and they insisted on paying for their time. We did not ask that, but they did it, and perhaps it was a good thing. It certainly was effective in tremendously boosting the interest of the boys.

One thing you men are interested in, of course, is the attitude of the state department of vocational education in this foundry work and in the other trade work. We are carrying this on under the Smith-Hughes Act and are getting reimbursement for about 35 per cent of our teaching cost from the state.

The only difficulty I see in our foundry work here in Cleveland in carrying on apprentice training, will be the selection of the right kind of boys. I worked at Granite City six or eight years, and I know that situation quite well. I believe it would be much easier to get boys interested in foundry work down there than it would be in Cleveland, although Cleveland has, of course, a large gray-iron industry.

However, our plan is started and it is working well. We have good cooperation from the state and we have part of our expenses paid by local industry. The local board of education has been very much interested because they have seen that we are doing practical work, satisfying the trade's demand. In other words, their money is going to the adequate training of the boys and functioning later on in their lives.

*Cleveland Trade School, Cleveland.

The support from the foundrymen themselves in contributions of supplies and material has been most unusual. The only problem we have now is to get out the right kind of news to the right kind of boys, so that they may come in and enroll and go through the preliminary year of training.

We take the boys for one year of preliminary training. At the end of that year, if they are successful, they are recommended to a foundry and a pair go out on the cooperative plan—that is, half time. They do not get into the half-day-a-week plan until the third year of their training course.

We really relieve the foundry of the burden of selection and of the expense of the first year's training, so that after we recommend a boy there is only about a five per cent chance of his failing when he gets out. Our success in the other trades is that about 95 per cent of the boys make good and stay put.

If we are that successful in the foundry, of course, I cannot see why the foundrymen should not continue to give us the support they have given in starting this training, because there is very close to $300 a year expense in training each boy during his first year in training. This should be encouraging to the foundries in Cleveland and the vicinity, and I wish to express to Mr. Fankhauser, who has been the active agent of the foundries, our appreciation of their whole-hearted support. We have had the personal attention of our foundrymen in Cleveland in pushing this work along.

WRITTEN DISCUSSION

L. T. GULICK:* One reason for concern in the foundry industry is embodied in the fact that desirable boys and young men are not being attracted in sufficient numbers as apprentices and junior executives to assure efficient operation and capable management in the years to come. Such a condition leads to an unfortunate state of affairs, because any industry which fails to interest young men who will eventually be capable of holding its prominent positions cannot realize attainment on a par with other industries. Failing in this, it will experience increasing difficulty in meeting competition.

Due to the fact that the present generation generally is more reluc-

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tant than preceding ones to enter types of work which involve hard manual labor, or which are otherwise unpleasant, certain other industries are in the same predicament as the foundry industry. Nevertheless, there are several reasons why the latter in particular has failed to appeal to aspiring youths.

One can be traced to the existing impression that all modern foundries operate in the same inefficient manner that their predecessors did. While obsolete practices still prevail in many plants, the number which have adopted modern up-to-date methods is fortunately constantly increasing.

Not many years ago, a real calamity seemed imminent because foundrymen had failed to keep up with the progress made in other lines. The impression still prevails in many quarters that obsolete and antiquated methods are the order of the day.

Actually, due to the efforts of trade publications, technical associations, manufacturers of equipment and interested individuals, and to the spur of competition, the foundry industry has taken a new lease on life. It has recognized its shortcomings and has set about to remedy them; but definite and aggressive steps must be taken to educate to that fact our boys and young men who show that they are interested in industrial pursuits.

There are four principal types of young men and boys who enter any industry: (1)—Those who leave the elementary schools usually because of the inability to meet its scholastic requirements, and who often proceed to "learn a trade" without further schooling. This statement does not reflect discredit upon the successful men in every branch of modern industry who left organized scholastic circles at an early age and have acquired their schooling through observation, experience and personal improvement. They are men of capacity and could easily have succeeded in school or college had they been properly guided and encouraged to stick to their tasks.

(2)—A second group comprises those members of our modern school population who have a bent for things mechanical and who stumble along through a certain amount of educational experience despite exposure to vocational guidance. Finally, after completing a high school training, they enter some trade as an apprentice without any real impression of what the foundry industry, or any industry other than the one they have chosen, has to offer.

(3)—The third group is made up of the graduates of our trade and vocational schools who have been trained in a particular trade which they are likely to follow in later life.

(4)—Under this grouping are found the graduates of technical institutions of college grade who have been instructed in the practical and theoretical phases of engineering practice but who, in most cases, have never been stirred to enthusiasm over the possibilities which lie in the foundry industry, and have never been encouraged to take up the business as their life's work.

It is from the second, third and fourth groups that the foundry

industry must plan to replenish its ranks and recruit its men of the future.

Many boys are not interested in entering the foundry field because their conception of a foundryman's work is erroneously formed. They believe that his principal duties consist of carrying molten metal in a hand ladle to a hand-rammed mold which he pours in an atmosphere of smoke and dust. While this is and always will be a picture of the industry under its worst conditions, these same boys should be shown by means of various forms of visual instruction and trips to up-to-date establishments that thousands of tons of castings are made yearly in desirable surroundings and under conditions which turn out products, as the saying goes, "untouched by human hands."

One condition that has dealt a severe blow to the entrance of boys into the foundry industry is the fact that foundry practice and pattern-making are no longer included in the curricula of many of our modern secondary schools unless the school is of the trade type. The tendency is to include only those courses which make the boy useful in the home and the producer of articles which his parents and the community will as the saying goes, "untouched by human hands."

It behooves manufacturers of foundry equipment and foundry leaders to educate the youth of our secondary schools and technical colleges to the possibilities of the casting business. We need courses of study in our schools which will faithfully reproduce the industry at its best, and financial encouragement of a sort that will attract young men after they know the possibilities.

Much splendid work has been done through the cooperative efforts of our industries and technical associations to determine the proper training for apprentices. What we need most of all is the propaganda necessary to render the public school officials, and the boys themselves, "foundry conscious." We must overcome the prejudices of the past and inspire modern youth to the possibilities in the foundry field. This can and must be done by the foundry industry itself.

Another reason for apprentice difficulties originates in the advertising schemes of certain competitive industries. In an effort to prove the superiority of their own wares, they have endeavored to depreciate the value of castings. As a result, the feeling has been created in the minds of the industrial public that the foundry is gradually becoming an historical relic, and that other manufacturing methods are rapidly superseding it.

While it must be admitted that many metal forms can be more economically produced in other ways, it is the opinion of those who know that there is still plenty of business for the foundryman and that competitive methods and "substitute" products can never entirely supplant castings.

However, even though the foundry industry is improving its practice, and although its proponents prophesy plenty of business in the future, the proper number and type of apprentices will not be attracted until misstatements have been corrected and its real advantages definitely presented. Definite and aggressive steps must be taken to show

that the castings business is a rich field for opportunity which can and will use all of the ingenuity and originality the engineering profession has to offer.

In advertising its product, it can well afford to take a few well chosen lessons from its competitors who have been actively engaged in stealing its market.

Chromium in Cast-Iron Mixtures

By T. F. Jennings,* Garfield, Utah

Abstract

The use of chromium in cast-iron mixtures as practiced in the past is described, and effects produced by varying combinations are discussed. Chromium, when added to the molten iron, is said to combine chemically with the carbon and iron, reducing the amount of graphitic carbon and closing the grain of the metal. Piwowarsky's findings as to the effect on hardness, strength, chilling tendency and resistance to abrasion are discussed. Chromium for general purposes is said to be most effective when under 1.00 per cent of the mixture. Transverse strength and deflection are usually augmented by additions of chromium up to 0.50 per cent. Results of various tests performed by the author are given.

1. Many interesting papers, describing the effects of chromium in cast-iron mixtures, have been presented before this and other technical associations in recent years and have merited the attention of practical foundrymen. A study of these papers indicates that an enormous amount of work has been involved in this investigation.

2. Results reported by investigators in various sections of this country and in foreign countries are remarkably consistent, considering such varying factors as method and speed of melting, quality and type of charge, sand conditions, etc. Any or all of these factors unquestionably influence the results. The papers which are given in the list appended to this paper cover the subject in a comprehensive manner.

3. While the present paper refers only to the effects of chromium, others have recorded the effects of chromium and nickel in various proportions. The ratio of these two elements should be approximately two parts nickel to one part chromium to effect a marked improvement in the strength of gray-iron castings.

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4. The silicon content and thickness of section, of course, must be taken into consideration. Considerable improvement in the strength of gray iron can be effected by the addition of either chromium or nickel. Briefly summarized, chromium increases the hardness, strength and wear-resisting properties of gray iron.

SOURCE OF CHROMIUM

5. In ordinary foundry practice, chromium is added to the charge in the form of ferrochrome, an alloy of chromium, iron and carbon and a product of the electric furnace. This alloy contains from 60 to 70 per cent chromium, 4.00 to 7.00 per cent carbon and the remainder iron. It is a heavy, dense alloy with a silvery fracture, usually is iridescent on the surface and melts in molten iron without much difficulty.

6. Even with small additions of chromium, changed structures of the iron are revealed by microscopic examination. The most perceptible change is in the size of the graphite flakes.

7. Formation of large flakes always is retarded. Depending on the analysis of the iron, as little as 0.25 per cent chromium sometimes is sufficient to render the iron pearlitic.

8. This is particularly important in present day practice where the trend in all recently improved processes is toward a eutectoidal cast iron. Chromium, when added to molten iron, combines chemically with carbon and iron, thus diminishing the amount of carbon which otherwise would separate as graphite flakes during solidification and which tend to soften the iron and promote an open grain structure.

9. Graphite, as it appears under the microscope, not only is decreased in amount but also is decreased in size. Chromium has more than a hardening effect. Indirectly, it closes the grain as well.

EFFECT ON CARBON

10. Formation of chrome-iron carbides at the expense of the graphite occurs with small additions of chromium and gradually increases until little free graphite is found where the chromium content is up to 3.00 per cent. The data of Table 1, as given by Piwowarsky, clearly show this effect of chromium in reducing the amount of graphitic carbon regardless of the silicon content.

11. These chemical analyses not only show the decrease in graphitic carbon with each small addition of chromium, but also show the corresponding increase in combined carbon. This is a point not to be overlooked, as the physical characteristics of the iron, hardness, strength, chilling tendency and resistance to abrasion depend, to a great extent, on the amount of combined carbon present.

12. A gradual improvement in strength accompanies the increase in combined carbon only to the point of eutectic composition, or about 0.80 per cent of combined carbon. Further additions of chromium convert more of the graphitic carbon to free cementite, the hardening constituent in iron, which accounts for the increase in hardness without corresponding increases in strength beyond certain points.

Table 1

EFFECT OF CHROMIUM ON CARBON CONTENT IN GRAY IRON AS GIVEN BY PIWOWARSKY

Silicon, per cent	Chromium, per cent	Graphitic carbon, per cent	Combined carbon, per cent
1.11	0.00	3.06	0.71
1.06	0.15	2.98	0.63
1.01	0.30	2.97	0.83
1.03	0.51	2.76	0.97
1.82	0.00	3.26	0.44
1.80	0.14	3.23	0.52
1.81	0.28	3.05	0.65
1.68	0.48	2.80	0.80
2.76	0.00	3.45	0.26
2.71	0.14	3.42	0.32
2.74	0.29	3.41	0.33
2.77	0.53	3.20	0.57

CHROMIUM CONTENT OF LESS THAN 1 PER CENT

13. Investigations have shown that certain limits exist in the quantity of chromium that may be added to cast iron if machinability is to be retained in a given thickness of section. These limits are raised with an increase in the thickness.

14. Some time ago the writer conducted a series of experiments in which cast-iron scrap was melted in an ordinary crucible with gradually increasing amounts of ferrochrome. Each heat was poured into 1-inch diameter test bars.

15. With iron containing carbon 2.86 per cent, silicon 2.72, manganese 0.50, sulphur 0.062, phosphorus 0.794, the maximum permissible addition of chromium before variation in case of machinability occurred was between 0.52 and 0.63 per cent.

16. Another investigator employed an iron analyzing carbon 3.16 per cent, silicon 1.48, manganese 0.97, sulphur 0.054 and phosphorus 0.70, and found that 0.40 per cent was the upper limit for chromium content. However, his results probably were influenced by the higher manganese content in the original iron.

17. These results may be open to criticism because the iron was melted in a crucible rather than in a cupola, and might not be considered a fair representation of what might be expected under different conditions. However, no special precautions were taken to refine the iron before casting. Consequently, it is just as logical to assume that more chromium might be added in regular foundry practice where every factor affecting quality has been carefully controlled before proceeding with the test.

STRENGTH AND DUCTILITY

18. Transverse strength and deflection usually are augmented by additions of chromium up to about 0.50 per cent, due in part to the refining action of the chromium in preventing separation of large graphite flakes. Where chromium additions between 0.50 per cent and 1.00 per cent are desirable and, simultaneously, high-strength iron is necessary, addition of nickel is suggested to restrain the effect of the excess cementite formed. This practice is not uncommon among foundrymen who have given these conditions some thought.

19. A series of chromium-bearing cast irons made some years ago at one of the leading universities and where the iron was melted in a cupola confirms the foregoing. The results are shown in Table 2.

20. Hardness, as shown by brinell numbers, was included in this summary to dissipate, in a way, a prevalent idea among foundrymen that an addition of more than 0.50 per cent chromium alone is objectionable from the standpoint of machinability.

21. With a lower silicon content and very light sections this is true; but where the lightest section is one inch or more,

hardness as might be expected is not in proportion to the amount of chromium added. Recently the author examined a block of cast iron five inches thick that contained only 0.40 per cent silicon and 1.68 per cent chromium. It had been drilled with a $\frac{7}{16}$-in. bit to demonstrate that, although a little difficult, it still was machinable.

RESISTANCE TO OXIDATION

22. Resistance to atmospheric corrosion or oxidation is improved slightly by small additions of chromium, but for a marked improvement more than 1.00 per cent should be added.

23. Small additions of chromium are advantageous if the castings are to be exposed to high temperatures. The strength

Table 2

EFFECT OF CHROMIUM ON STRENGTH AND DUCTILITY OF GRAY IRON

Analysis						Transverse strength—18-in. centers	Deflection—in., 18-in. centers	
Carbon	Chr	Si	Mn	S	Ph			Brinell
3.74	0.08	2.18	0.53	0.074	0.460	1892	0.186	156
3.60	0.20	2.35	0.62	0.063	0.474	2056	0.216	183
3.84	0.35	2.20	0.53	0.057	0.374	2515	0.233	196
3.92	0.48	2.29	0.48	0.062	0.288	2498	0.225	212
3.69	0.69	2.02	0.50	0.048	0.364	1635	0.148	183
3.84	0.81	2.34	0.56	0.057	0.266	1952	0.256	187

at elevated temperatures is improved definitely even with less than 0.40 per cent chromium. Such small additions prevent softening after prolonged exposure at 1700 degs. Fahr. Higher percentages reduce the loss due to oxidation materially.

24. In addition to these properties, it has been proven that chromium definitely retards castings growth when repeatedly heated and cooled, thus materially improving iron castings used where stresses of this nature are encountered. The writer plans to conduct tests on the use of chromium as an alloying agent in heavy chill blocks that, after repeated use, usually become fire-checked, thereby reducing their life.

25. As the amount of chromium is increased beyond an

addition of 1.00 per cent, the hardness is increased very rapidly. Only at rare intervals are alloyed irons found containing between 1.00 per cent and 3.00 per cent chromium unless the casting has been designed to resist abrasion in some form or other.

26. To measure the effect of chromium on volume shrinkage, we decided to cast relatively heavy blocks (5x5x25 in.) in sand and weigh them after cooling, assuming that such a procedure would at least indicate the size of the pipe cavity caused by the natural shrinkage of the metal. The results we obtained follow:

Sample.	Chromium, per cent.	Weight, lbs.
A	0.00	78.5
B	0.37	78.0
C	1.68	80.0

27. From these results it appears that chromium-alloyed irons certainly do not seriously affect the final shrinkage. No way of measuring specific gravity was available, but it is reasonable to assume that an iron which contains chromium iron carbides instead of graphite must be heavier per unit size.

Table 3

EFFECT OF CHROMIUM ON FLUIDITY OF GRAY IRON

Test	Chromium, per cent	½-in. section	¼-in. section	⅛-in. section
A	0.00	full	full	full
B	0.37	full	full	75%
C	1.68	full	full	25%

FLUIDITY TESTS

28. In attempting to measure fluidity, we decided to pour several flat castings ½-in. thick about 10 in. square, and reduced in 1½-in. steps to ¼-in. and ⅛-in., respectively, at one end.

These were poured with the steps on the cope side and opposite the gate. The results appear in Table 3.

29. This home-made method of determining the fluidity, while perhaps unscientific, indicates just what we all want to know. Can such thin sections as are met in the foundry be poured successfully? The answer is shown in this chart. The metal must be hotter than ordinary soft iron, as chromium exerts a deadening effect.

30. Iron containing more than one per cent chromium finds its greatest use in abrasion resistance work, which is a problem common in grinding, conveying and crushing machinery. When applied to these problems with a consideration of its low cost compared with more expensive alloys, its utility and possibilities are readily appreciated.

31. In view of the relative costs of pig iron and scrap steel, we find it advantageous to use high percentages of steel scrap. This practice was described by the author some years ago, in a paper[1] presented before the American Foundrymen's Association and reproduced in *The Foundry*, vol. LIV, page 779. Two mixes are used, both balanced in respect to chromium and silicon content.

Table 4

MIXTURES USED BY ONE FOUNDRY IN CASTING GRAY IRON

No. 1		No. 2	
Material	Lbs.	Material	Lbs.
Steel scrap	3750	Returned scrap	4000
Soft iron scrap	1250	Soft iron scrap	1000
Ferrochrome	150	Ferrochrome	100
Coke	800	Coke	800
Limestone	150	Limestone	150
Purite	20	Purite	20

32. These charges, 10 to 12 each day, melt down with approximately a 20 per cent chromium loss. The iron is very low

[1] *Melting All Steel Charges in a Cupola Furnace.* TRANS., A. F. A., Vol. 34, pp. 1011-1029 (1926).

in silicon, resulting from the high steel portion of the charge, but we find this is a very important factor in the quality of the metal. With more silicon the hardness would be lowered, and if any change were considered at all, we would favor increasing the amount of ferrochrome.

33. Through the work of other authors and contributors to technical literature, we find that chromium definitely improves cast iron, first, with an increase in strength and hardness, and second, with higher additions, with a rapid increase in hardness at the sacrifice of ductility.

34. The author is aware of the shortage of more exact data relative to the qualities imparted by this agent, but is firmly convinced that if given a thorough trial with technical supervision, its use will increase rapidly in the future.

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Deep-Etch Test of Brass

By W. F. Graham * and L. A. Meisse,* Mansfield, Ohio

Abstract

While investigation of ferrous metals by so-called deep etching has been applied extensively in recent years, very little has been published on this method of investigating nonferrous metals. This paper describes some typical results along these latter lines. A smooth surface of metal is given a rather violent treatment by reagents which eat away the points or areas of discontinuity of the structure. Application in the authors' laboratory was confined largely to cast red brasses, and the proper reagent to use is nitric acid. The deep etch is said to reveal not only inclusions and character of metal from oxidized or reduced standpoint, but also porosity, laminations or actual fissures which are not visible to the eye in the unattacked fracture. The information gained provides a means for the foundryman to survey conditions causing defects and to make the necessary corrections in his melting and molding practice.

Introduction

1. The investigation of ferrous metals by means of so-called deep etching and subsequent macro-examination of the surface has been applied extensively in recent years. In the literature there may be found well-illustrated examples of the results of this test, as shown by Keshian,[1] but there seems to be little work done in its relation as a tool for the uncovering of defects in nonferrous metals and alloys. In this paper it is attempted to describe briefly some typical results obtained in deep etching these latter materials, especially the brasses and bronzes to bring out more clearly defects in the metal which otherwise would be invisible to the naked eye.

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[1] *Deep-Etch Test for Iron and Steel.* Trans. American Society for Steel Treating, vol. XII, p. 689 (1927).

Test Procedure

2. Deep etching is accomplished by the attack of reagents which will react rather violently with a smooth surface of the metal or alloy. The reagents tend to eat away the points or areas of discontinuity of the structure, which may be caused by sonims, crystal boundaries and, in certain materials, by dendrites.

3. In general, the clean metal as represented by the mass of the crystals is not attacked. The degree of the attack of the reagents will, of course, vary with concentration, time and temperature.

4. The test procedure should be so adjusted that the attack does not progress to such an extent that the results of the differential etch of the inclusions is over-emphasized. It is the object of the test to reveal the presence of inclusions; and, after they have been revealed so that they are visible to the eye or under low magnification, there is no further necessity of developing them by continued etching.

5. The actual mechanics of the attack may be explained by the common electrolytic theory of corrosion in which there is a couple set up between the dissimilar constituents in the matrix.

6. In the case of nonferrous alloys, the etching attack may proceed on dissimilar constituents which may be forced out at the grain boundaries. In all cases, however, in the application of this test the body of the crystal, even though composed of a solid solution of a cored nature, will be in a slight relief to that of the grain boundary. The grain boundary will be traced slightly by the etching reagent and if there are no inclusions the specimen will have the appearance of a mass of clean bright crystals.

APPLICATION OF DEEP ETCHING TO RED-BRASS ALLOYS

7. Our application and experience with deep etching has been confined chiefly to investigation of the structure of cast red brasses, that is, alloys containing copper, tin, lead and zinc of the approximate composition 85-5-5-5 and variations thereof. We have, however, applied the method in some cases to yellow brasses, phosphor-bronzes, gun metal and some special nonferrous alloys, and the results which we obtained were very satisfactory.

Reagents

8. It would seem that the proper etching reagent to use on red brasses is nitric acid. Nitric acid attacks the alloy violently, generating a considerable amount of heat. For this reason the action is a very quick one and the test can be accomplished in a very short time.

9. In the use of concentrated nitric acid alone it was found that the tin, particularly when over two per cent, was oxidized to meta-stannic acid. This insoluble coating promoted a differential attack which was misleading.

10. In order to overcome this difficulty, 10 per cent of hydrochloric acid was added to the etching reagent, thereby keeping the tin oxide in solution and thus resulting in a clean surface on the specimen.

Procedure

11. The actual procedure in etching a given specimen depends somewhat on its size and shape, but for specimens not greater than 3 in. square and ½ in. thick, we have found that an 8-minute immersion in a solution of nitric acid (1.42 spec. grav.) with an addition of 10 per cent by volume of hydrochloric acid (1.18 spec. grav.) gives, in general, a very satisfactory etch.

12. The method can be varied and used to investigate the structure of quite large specimens by means similar to those used for the whole surface of steel ingots. Etched surfaces which have tarnished can be brightened by washing in chromic acid.

EXAMPLES OF DEEP-ETCH SPECIMENS

13. Fig. 1A illustrates a specimen that is considered a very good red brass. The section was taken from composition ingot containing copper 80.62 per cent, tin 3.33, lead 6.93, zinc 8.82, iron 0.13, antimony 0.17, manganese nil and phosphorus nil. It will be observed that the only differential attack visible is on the grain boundaries of the crystals, with the exception of a slight trace in the portion which might be termed pipe.

INCLUSIONS

14. Fig. 1B shows material of the same sort having an analysis of copper 86.93 per cent, tin 2.77, lead 3.39, zinc 6.74, iron 0.10, antimony 0.07, manganese nil and phosphorus nil. The indications are that this lot of ingot is not as free from

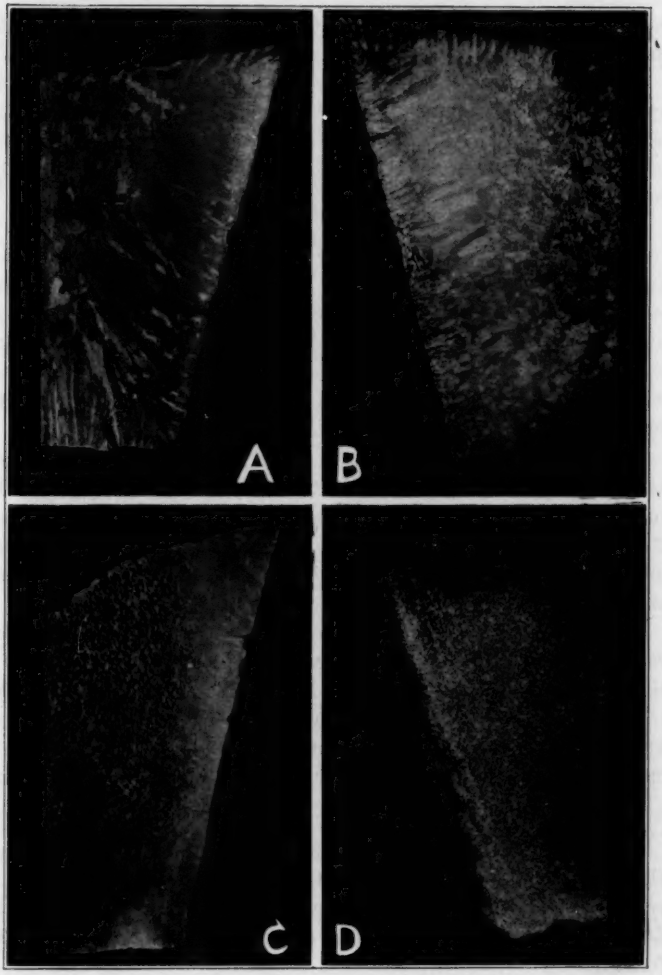

FIG. 1—DEEP-ETCHED SECTIONS FROM RED-BRASS COMPOSITION INGOT, SHOWING ATTACK ON GRAIN BOUNDARIES OF CRYSTALS, AND TRACE IN "PIPE" PORTION. ANALYSIS:

A—CU 80.62; SN 3.33; PB 6.93; ZN 8.82; FE 0.13; SB 0.17.
B—CU 86.93; SN 2.77; PB 3.39; ZN 6.74; FE 0.10; SB 0.07.
C—CU 79.2; SN 3.7; PB 7.01; ZN 9.83; FE 0.10; SB 0.16.
D—CU 83.74; SN 5.20; PB 5.04; ZN 5.85; FE 0.13; SB 0.04.

inclusions as that shown by Fig. 1A. It is our feeling that it contains a considerable amount of oxide, presumably in the form of zinc oxides.

15. Fig. 1C represents an etched section which is of poor appearance. This ingot contained copper 79.2 per cent, tin 3.7, lead 7.01, zinc 9.83, iron 0.10 and antimony 0.16. The center portion obviously contains more inclusions than the areas adjacent to the edges.

16. Fig. 1D is of composition ingot having analysis of copper 83.74 per cent, tin 5.20, lead 5.04, zinc 5.85, iron 0.13, and antimony 0.04, in which we have an etching attack of the whole surface. In this case it would seem that the condition is caused by an over-reduction of the metal in the refining process. There are apparently impurities or compounds forced out to the grain boundaries, thereby promoting the differential attack of the reagent.

17. The four specimens of Fig. 1 represent metals alloyed and cast with a minimum of influencing factors other than the furnace conditions during the melting and refining of the metal. The deep-etch method of test, however, when applied to metals or alloys subjected to further influences such as casting into molded shapes, reveals other conditions in the structure.

18. Aside from impurities or other influencing factors resulting from the melting—the casting of the alloy into irregular shapes, running the metal over the sand, the rate of pouring the casting and the temperature at which the metal is poured—may at times bring about effects in the resulting solid metal which can be shown by a deep etch of a section taken from the casting.

Porosity and Fissures

19. The deep-etching test will not only reveal inclusions in the casting and character of the metal from an oxidized or reduced standpoint, but also porosity, laminations or actual fissures which are not visible to the eye in the unattacked fracture.

20. Fig. 2A illustrates blow-holes and other unsoundness in the boss of a casting from an alloy of the approximate composition of 84 per cent copper, 3 per cent tin, 3 per cent lead and 10 per cent zinc.

21. We have found a considerable number of inclusions in red brass of the composition 81.5 per cent copper, 3 per cent tin.

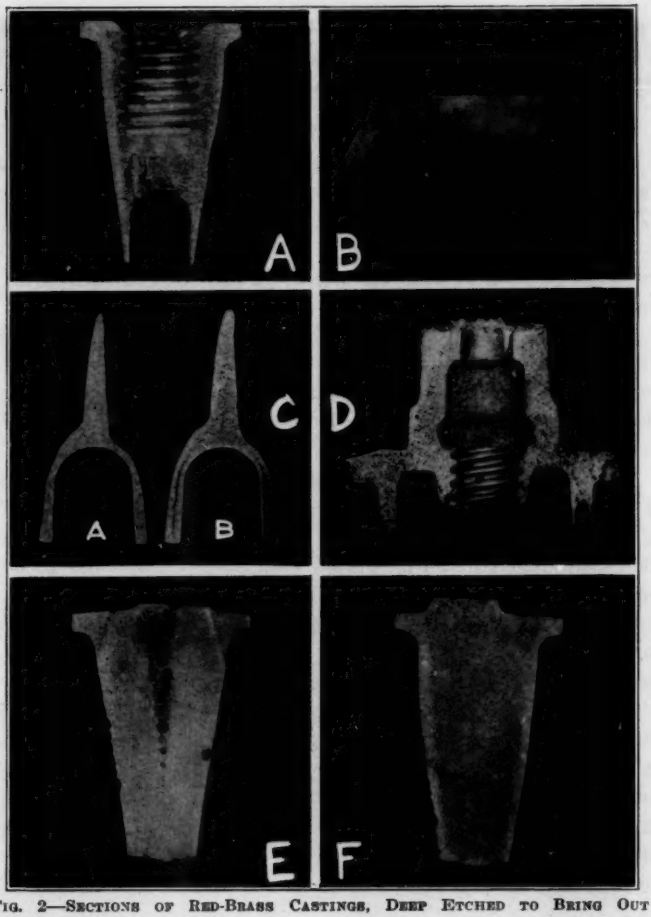

FIG. 2—SECTIONS OF RED-BRASS CASTINGS, DEEP ETCHED TO BRING OUT DEFECTIONS MORE CLEARLY.

A—BLOW-HOLES AND OTHER UNSOUNDNESS IN BOSS. APPROXIMATE ANALYSIS: CU 84; SN 3; PB 3; ZN 10.

B—INCLUSIONS IN HEXAGON PORTION OF RED-BRASS VALVE BODY, MELTED IN OPEN-FIRE FURNACE. APPROXIMATE ANALYSIS: CU 81.5; SN 3; PB 7; ZN 8.5.

C—EFFECT OF VERY HOT POURING ON LIGHT-SECTION CASTINGS. "A" IS SOUND CASTING; "B" IS DEFECTIVE, SHOWING ATTACK AT JUNCTURE OF COLUMNAR CRYSTALS. APPROXIMATE ANALYSIS: CU 87.75; SN 5.5; PB 1.75; ZN 5.

D—IRON INCLUSIONS REVEALED, CAUSING MACHINING DIFFICULTIES. ANALYSIS SAME AS FOR *B*.

E—SHRINK IN BOSS OF TROLLEY EAR, NOT OTHERWISE VISIBLE THAN BY DEEP ETCHING.

F—SAME CASTING AS *E*, BUT SHOWING POROUS CONDITION THROUGH ENTIRE SECTION.

7 per cent lead and 8.5 per cent zinc melted in an open-fire type of furnace, as illustrated by Fig. 2B, showing the section of the hexagon portion of a valve body.

Effect of Hot Pouring

22. The effect of very hot pouring on light-section castings made from composition of copper 87.75 per cent, tin 5.50, lead 1.75 and zinc 5.00 may be seen in Fig. 2C. Specimen *A* of Fig. 2C is a sound casting and Specimen *B* is a defective casting, which the deep etching reveals by attacking the juncture of the columnar crystals.

23. Contamination of red brass by iron promotes serious difficulty in the machining operation. Fig. 2D illustrates a section of a casting of the same composition as that in Fig. 2B, in which there are considerable iron inclusions revealed by deep etching.

24. The actual character of metal is not wholly revealed by fracture nor by examination of the machined surface. Fig. 2E shows the shrink in the boss of a trolley ear which was not otherwise visible, and Fig. 2F shows a porous condition through the whole section; both of these conditions are revealed by deep etching. Figs. 3A and 3B reveal shrinkage and porosity in sections of a trolley-wheel casting of approximately copper 94.7 per cent, tin 5.00 and phosphorus 0.3 per cent.

25. Considerable difficulty was experienced at one time in properly casting an alloy of composition of copper 94 per cent, tin 2 per cent, lead 3 per cent and zinc 1 per cent. Fig. 3C illustrates a gassy condition of a section cut from the casting, while Fig. 3D is that of a good casting. In both specimens considerable difficulty would have been experienced in differentiating between the unsatisfactory and satisfactory metal. The deep etching reveals the nature of the trouble immediately.

Determining Causes of Defects

26. The application of the deep-etching test as a means of determining the exact cause of certain foundry difficulties is well illustrated in Fig. 3E. The deep-etched section of the casting as shown by Specimen *A*, Fig. 3E, indicates sound metal, but until the deep-etch test was performed, considerable doubt as to the character of the metal was generated by examination of the rough surface, as shown in Specimen *B*, which is the other half

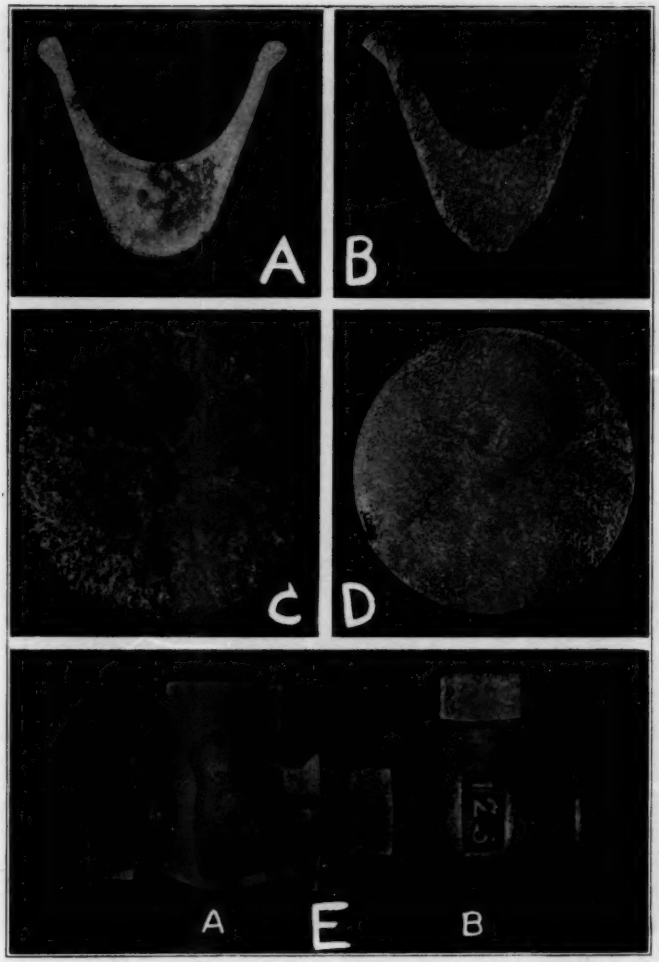

FIG. 3—APPLICATION OF DEEP ETCHING TO REVEAL SPECIFIC DEFECTS IN RED-BRASS CASTINGS.

A AND *B*—SHRINKAGE AND POROSITY IN SECTIONS OF TROLLEY-WHEEL CASTING. APPROXIMATE ANALYSIS: CU 94.7; SN 5; P 0.3.

C AND *D*—DEEP ETCHING TO DIFFERENTIATE BETWEEN SATISFACTORY AND UNSATISFACTORY METAL. "C" SHOWS GASSY CONDITION OF SECTION; "D" SHOWS GOOD SECTION FROM SAME CASTING. APPROXIMATE ANALYSIS: CU 94; SN 2; PB 3; ZN 1.

E—DETERMINING EXACT CAUSE OF FOUNDRY DIFFICULTIES. EXAMINATION OF ROUGH SURFACE OF CASTING, AS IN "B," CREATED DOUBT AS TO CHARACTER OF METAL. "A" SHOWED SOUND METAL, REVEALED BY DEEP ETCHING, PROVING THAT DEFECT WAS CAUSED BY CONDITIONS OTHER THAN QUALITY OF METAL.

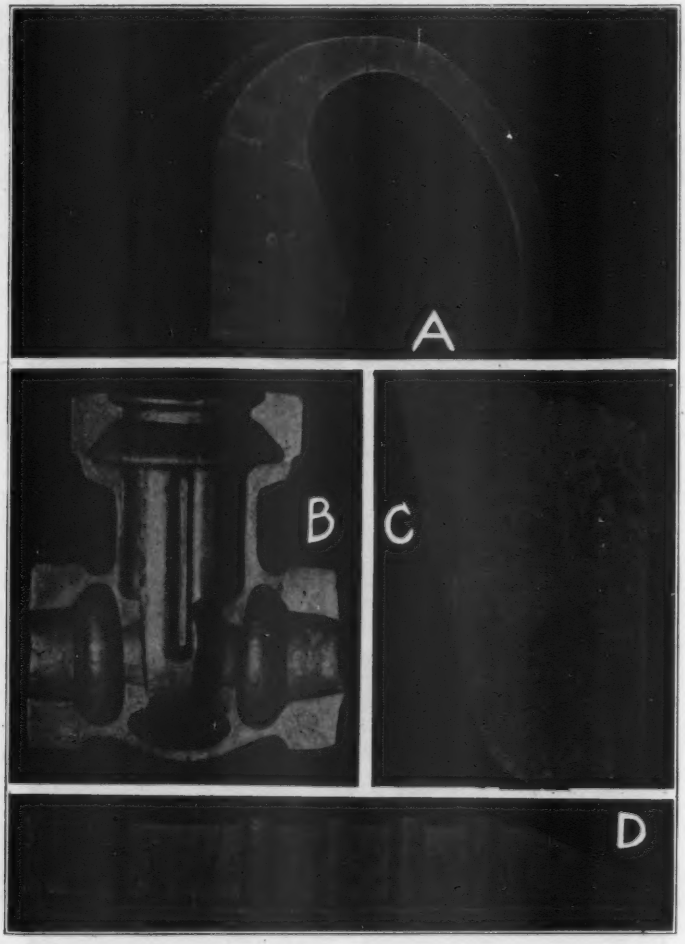

FIG. 4—MISCELLANEOUS APPLICATIONS OF DEEP ETCHING.

A—ALUMINUM-BRONZE GLIDER CASTING, SHOWING VERY SOUND AND CLEAN METAL.

B—CLEAN METAL REVEALED IN VALVE CASTING; COMPOSITION OF METAL SIMILAR TO THAT SHOWN IN FIG. 2*B*.

C—DEEP ETCHING OF SOUND AND CLEAN YELLOW BRASS APPARENTLY GIVES SAME RESULTS AS WITH RED BRASS. SECTION OF YELLOW BRASS COMPOSITION INGOT.

D—EFFECTS OF FAULTY GATING IN DIFFICULT CASTING FED IMPROPERLY. FRACTURE FAILED TO DISCLOSE POROSITY WHICH DEEP ETCHING UNCOVERED.

of the same casting. The defective casting obviously was the result of conditions other than those pertaining to the quality of the metal.

Application to Aluminum-Bronze and Yellow Brasses

27. The application of the deep-etch test to other alloys than red brass is shown by Fig. 4A, which illustrates the section of an aluminum-bronze glider casting. This particular alloy and casting are remarkably sound and clean in the section shown in the photograph.

28. An illustration of rather clean metal in a valve casting, similar in composition to that shown in Fig. 2B, is shown in Fig. 4B. Sound, clean yellow brass seems to deep etch with about the same results as sound, clean red brass. An example of this is shown in Fig. 4C, which illustrates a section cut from a yellow-brass composition ingot.

29. The effects of faulty gating, which did not properly feed a rather difficult casting to make, is shown by the deep-etched section illustrated in Fig. 4D. The fracture did not reveal the areas of porosity which were uncovered by the deep-etch attack.

Dirty Metal

30. Specimen *A* in Fig. 5A illustrates a casting taken from a very "dirty" heat rejected on the floor of the foundry. The cause of this condition is not fully uncovered, although it may have been brought about by an oxidizing condition in an open-flame furnace, combined with a certain amount of impurities in the original charge.

31. The "dirty" condition of the surface of the casting went hand-in-hand with the dirty condition of the interior of the metal as shown by the deep-etch sections of Specimens *B* and *C* in the same illustration. The sound structure of the section of yellow-brass ingot shown in Fig. 4C may be compared with the remarkably unsound condition of the structure of an experimental yellow-brass heat illustrated in Fig. 5B. The deep etch of this section reveals a remarkably oxidized condition of the metal.

32. Three conditions of red brass as brought about by the melting conditions are illustrated in Fig. 5C. The three speci-

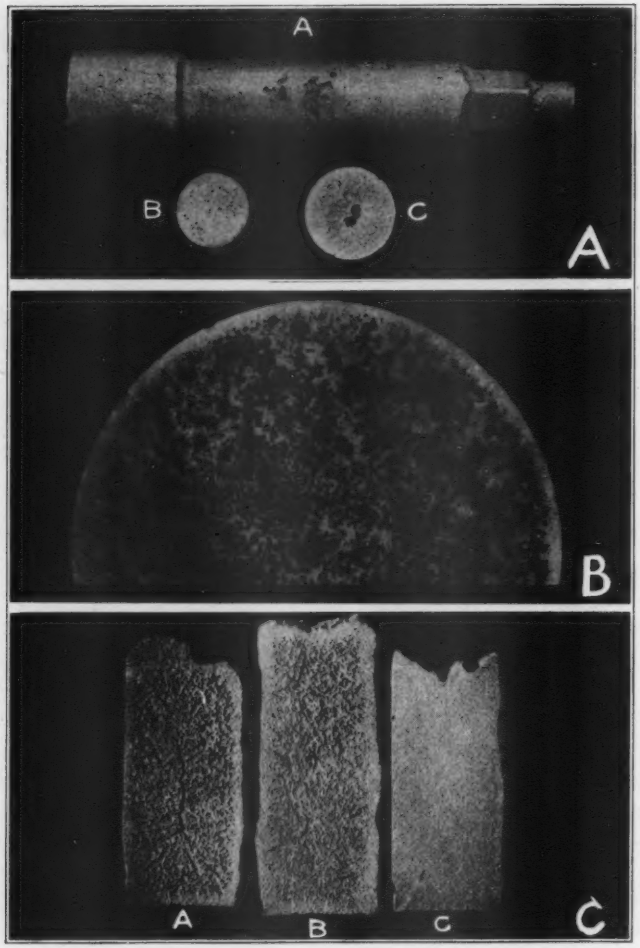

FIG. 5—OXIDATION IN BRASS CASTINGS, AND IMPROPER FOUNDRY CONDITIONS, AS REVEALED BY DEEP ETCHING.

A—CASTING FROM A "DIRTY" HEAT REJECTED ON FOUNDRY FLOOR; PROBABLY CAUSED BY OXIDIZING CONDITIONS IN OPEN-FLAME FURNACE AND IMPURITIES IN CHARGE. "A" SHOWS DIRTY SURFACE CONDITION; "B" AND "C" SHOW SAME CONDITION IN INTERIOR OF METAL.

B—HEAVILY OXIDIZED CONDITION UNCOVERED IN YELLOW-BRASS CASTING FROM EXPERIMENTAL HEAT. COMPARE WITH SOUND STRUCTURE OF SECTION IN FIG. 4C.

C—THREE CONDITIONS OF RED BRASS CAUSED BY FURNACE CONDITIONS IN MELTING UNDER REDUCING, OXIDIZING AND "NEUTRAL" ATMOSPHERE. "A" SHOWS FISSURES IN INTERIOR, UNCOVERED BY DEEP ETCHING REDUCED CONDITION; "B" SHOWS PRESENCE OF OXIDATION; "C" REVEALS UNIFORM STRUCTURE TYPICAL OF SOUND RED BRASS.

mens, *A*, *B* and *C* of Fig. 5C show deep-etching sections of castings from experimental heats melted under reducing, oxidizing and so-called neutral atmosphere. In Specimen *A* the fissures in the center of the casting are revealed by the deep etch of the so-called reduced condition. In Specimen *B* deep etching shows the presence of oxidation, while in Specimen *C* there is illustrated a uniform structure which is quite typical of sound red brass.

Conclusions

33. It has not been our intention in this paper to discuss at any great length the application of this test as a means of control by the foundryman of the quality of material that he may purchase or produce. We do desire, however, to record the fact that our application of this test as applied to composition ingot has resulted, we believe, in a benefit in respect to the quality of the material.

34. A number of the refiners of secondary composition ingot are now making some use of this method as a control of their furnace operations, and our routine deep-etch tests of incoming shipments of ingot within the last year have indicated that there is a general improvement in the quality of the red-brass alloy with respect to the presence of oxides and other inclusions in the castings.

35. With respect to the results obtained by the test in the foundry, it is obvious that the porosity in castings can be determined quickly by the etching of sections. In standardization of melting practice, tying back to the character of the raw materials used as melting base, the deep-etch test is not only of interest but of positive value.

36. Unfortunately, red brasses are not sound materials in general, when examined from edge to edge; but, very fortunately, there is a sound skin at least on the edges of the casting section. If it were not for this latter condition, the foundryman would have a great deal of difficulty in producing a casting which would meet pressure test.

37. In order to overcome some of the extreme conditions which may cause trouble due to the porosity of the interior of the metal, it will be found that the application of the deep-etch

test will provide a means for the foundryman to survey this condition and make the necessary corrections in his melting and molding practice.

DISCUSSION

ORAL DISCUSSION

W. F. GRAHAM: This paper simply describes a method for determining many of the debatable defects which may be found in nonferrous castings. The deep-etch method of testing is not new. It is employed extensively in steel manufacture and use, but we have found that there is very little published in the literature pertaining to nonferrous work regarding this method of attack.

The foundryman—the metallurgist—interested in nonferrous castings frequently have brought to their attention defective castings in which the defects are debatable. In our opinion, the tool which we have here—the deep-etch test method—is a very promising one to clear up some of these questionable points.

We have not attempted in this paper to settle any of these points. We have merely described the method of test and have showed a few illustrations picked at random from several thousand specimens of defective castings which we believe to be representative of certain dissimilar conditions producing either defective castings or, possibly—without getting into this debatable point—composition ingot material which may not be so desirable, depending on the individual point of view.

Briefly, the test consists in taking the sawn or roughly ground section of a casting, or of a composition ingot, and immersing it in concentrated nitric acid. We have found that a little hydrochloric acid added to the nitric acid will dissolve the tin oxide or metatanic acid which is thrown out as a white precipitate on the surface and which may obscure the result. It can be used either with or without the hydrochloric acid, depending on the composition, the amount of tin.

The time of immersion in the acid may be about six to ten minutes, depending on the size of the piece and how deep it is desired to etch it. Take out the specimen, wash it off, look at it—that is all there is to the method.

CHAIRMAN J. W. BOLTON*: Mr. Graham, have you applied the method you describe to the study of defectiveness of gates and risers?

*The Lunkenheimer Co., Cincinnati.

W. F. GRAHAM: Specifically, we have recently made use of this method of test to determine the soundness of test bars. The question of the proper test bar has been debatable for a long time. We ourselves have used different designs, and some of my assistants made up several types of test bars, gated differently. They sawed them, etched them in acid and revealed absolutely conclusively why certain patterns for test bars, gated certain ways, gave low physical properties, whereas other patterns gave high physical properties, out of the same metal.

In other words, they showed that either the gating or the risers or distance of travel on ends of the test specimen are too long to feed up the shrink that exists in the gage section. That is a specific example of the use of the test.

MEMBER: At what magnification did you work in examining these specimens?

W. F. GRAHAM: No magnification at all. You do not have to have any magnification to see the condition of the metal.

W. M. BALL:* On this deep-etching, can you locate anything other than over-oxidized or over-reduced condition, such as impurities, in a complex analysis where we have sulphur and nickel and antimony and these other impurities present?

W. F. GRAHAM: Any of the elements—nickel, for instance, which is not necessarily harmful at all—that go into solution with any of the main constituents of brass are going to be part of the grain itself, and are not revealed by the deep-etch test.

In general, the deep-etch test shows solid non-metallic impurities. Mr. Hibbard's name for that is sonims; it has been used in the steel industry for a long while. It may also reveal the gas holes which may be caused by one type of gas or another.

To put it another way, deep-etching shows a discontinuity of structure, a void or incipient void, where there will be a weakness or a cavity to permit gases under pressure, or water or liquid, to pass out, or where the specimen will break.

G. H. CLAMER:† It would be unfortunate if the members present did not take home with them the most important point brought out by this deep-etch test—that probably more metal is spoiled by following the practice that has for years been considered the cure-all (the use or excessive use of charcoal) than by any other cause.

Copper refiners, since copper refining began, have always recognized the fact that an over-cold copper was decidedly inferior for making copper-base alloys than was a slightly oxidized copper. If the foundryman takes this carefully controlled copper and mixes alloys and puts in an excessive amount of charcoal, or melts in an excessively reducing atmosphere, there is an absorption of CO gas which results in porosity, and a red flag should be raised against the much practiced use of charcoal.

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*Edna Brass Mfg. Co., Cincinnati.
†Ajax Metal Co., Philadelphia.

If the members here will remember that and, when they get into porosity troubles, if they will go over to an oxidizing condition, they will frequently eliminate the trouble which they have been attempting to correct by adding charcoal.

CHAIRMAN J. W. BOLTON: This deep-etch test method is equally useful in forged or extruded products. Where there are undue strains, cracks, etc., they are brought out by this method.

A. W. LORENZ:* Mr. Graham, can you explain the fact that you have less of a columnar structure with your reduced condition than you do with the oxidized condition, or do you merely know that that happens to be the case?

W. F. GRAHAM: I would not say that there is less columnar condition; that depends on the degree of either one of the conditions. In general, I agree with Mr. Clamer: If a metal is gassed, so much gas, generally, will be made—a condition from edge to edge. Less gas, and possibly some reduced condition, might be obtained only in the center.

WRITTEN DISCUSSION

H. G. KESHIAN:† This valuable contribution by the authors will be greatly appreciated by every one who is deeply interested in sounder and better materials. The deep-etch method described in the paper no doubt will accomplish much the same thing in the field of nonferrous metals as the similar method has been doing recently in the field of iron and steel.

I thoroughly agree with the authors in their belief that deep-etch test will reveal defective and unsatisfactory structure in brasses and bronzes. In the meantime, without desiring to detract from the value of this excellent paper, or disagree with its authors, I wish to sound a small but important warning in regard to the proper use of this method of testing, which has been brought out quite forcibly in our experience with deep-etch test for iron and steel.

The beautiful illustrations given in the paper clearly show the difference between a sound and unsound casting. This difference, however, is not always so clearly brought out. Very often it happens that the structure disclosed by deep-etch test cannot unreservedly be called good or bad without resorting to additional tests of different nature, such as microscopic examination or physical test. Without proper caution there is present almost always a bit of danger to be arbitrary on the part of the person who uses the test.

It is quite true that this caution should be exercised in any method of testing, but this is particularly true in the case of deep-etch test.

*Bucyrus-Erie Co., South Milwaukee, Wis.
†Waterbury Mfg. Co., Waterbury, Conn.

The reason for this seems to lie in the fact that, while the results of many other tests can be expressed in numerical values, those of the deep-etch test cannot be so expressed.

For instance, if it is a chemical test, the amount of elements present in the metal can be stated by percentages. If it is a tensile test, the results can be indicated by so many pounds per unit section, or elongation in so many inches, etc. In the deep-etch test, unfortunately, we cannot express the results in numerical terms.

For instance, what is the size and the number of blow holes or segregations in any casting which would render that particular casting defective or unsatisfactory? Under varying sets of conditions the answer will also vary, demanding a careful weighing of many other factors that enter into the decision.

Again, at times certain variations either in the rate of pouring or cooling of the molten metal, or some slight change in its chemical composition, can appreciably alter its deep etching characteristics, which may not materially affect its physical properties. The greatest value of the deep-etch test lies in its correlation with other tests rather than in its independent use.

Effects on Cast Iron of Prolonged Heating at 800-1100 Degs. Fahr.

By R. S. MacPherran* and Rexford H. Krueger,** Milwaukee

Abstract

The investigation described here was undertaken for the purpose of determining the effect upon cast irons of long-time high-temperature operations. Various types of cast iron were heated for 500 hours at temperatures up to 1100 degs. Fahr., after which physical and chemical tests were made to determine the effect of such treatment. Some of the authors' conclusions were that high silicon materially accelerates decomposition of pearlite, and that nickel does the same, although to a lesser extent. Low silicon and low carbon with finely divided graphite flakes tend to delay this action. Chromium decidedly increases tensile strength at room temperatures and delays decomposition of pearlite. It also operates to hold up strength at high temperatures.

1. Owing to prospective higher temperatures of operation it has become necessary to know the effect on various types of cast iron of a long-time hold at high temperatures. It has also become desirable to know what types of cast iron best resist the softening or annealing effect of high temperature. Our question was, in fact: What is the tensile strength of cast iron in general and of high-test cast iron in particular when operating at high temperatures? Two factors must be considered, namely, time and temperature.

Earlier Investigations

2. In some work done in 1922 on annealing gray cast iron,[1] we found that holding cast iron at 1050 degs. Fahr. for three hours had no material affect upon its hardness or strength. While this treatment has been satisfactory for the relief of

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**Assistant Chemist, Allis-Chalmers Mfg. Co.

[1] Harper, J. F., and MacPherran, R. S., *Annealing Gray Cast Iron*, Trans., American Foundrymen's Association, vol 30, pp. 167-180 (1922).

casting or machine strains, the time is entirely inadequate to determine the effect of a long-time service. Considerable work has been done on heating of cast iron by various investigators, but space forbids the mention here of more than a few of these investigations.

Work on Repeated Heating and Cooling

3. Among the best known are, perhaps, Carpenter and Rugan[2] and C. E. Pearson.[3] The former find that repeated heating and cooling has a greater effect than one continuous heat. Both of the above, however, conducted most of their tests above 1500 degs. Fahr., which range is not touched by this paper.

4. O. W. Potter[4] finds that annealing at 500 degs. Fahr. slightly increases strength of most irons.

Data on Low-Temperature Heat Treatment

5. The work of J. W. Donaldson on low-temperature heat treatment deserves special mention. In his three papers[5, 6, 7] he has covered the field in detail and with great thoroughness. Donaldson finds that high silicon, high carbon and nickel tend to accelerate the decomposition of pearlite when heated at high temperatures; that low silicon, chromium, low carbon, and also phosphorus and manganese to a lesser extent, tend to stabilize the carbide and delay this action.

6. He finds also a decided softening effect when heating at 840 degs. Fahr. for 200 hours with a cooling after each eight hours of heating. His method of procedure was to heat eight hours and cool overnight, repeat the heating and cooling the next day and continue until his desired total of 200 hours had been reached.

7. Our results above referred to agree with the findings of Potter, and the results of this paper tend to agree with those of Donaldson.

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[2] Carpenter and Rugan, Jnl. Iron and Steel Institute (1909).

[3] Pearson, C. E., *Growth of Commercial Gray Cast Iron*, Iron and Steel Institute, Carnegie Scholarship Memoirs, vol. xv, 1926.

[4] Potter, O. W., *Heat Treatment of Gray Cast Iron*, A. F. A. Belgian Exchange Paper, 1927.

[5] Donaldson, J. W., *Low-Temperature Heat Treatment of Special Cast Iron*, Foundry Trade Journal, June 18, 1925.

[6] Donaldson, J. W., *Heat Treatment and Growth of Cast Iron*, Foundry Trade Journal, Feb. 17, 1927.

[7] Donaldson, J. W., *Heat Treatment and Volume Changes of Gray Cast Iron between 15° and 600° C.*, Foundry Trade Journal, Oct. 25, 1928.

Scope of Investigation

8. The authors wished to vary the detail of this procedure by longer continuous holds at various temperatures and to run tests on the irons actually used in our own foundry, particularly on high-test iron.

9. On repeated heating and cooling, the effect of heat itself is reinforced by possible action of gas penetration and oxidation. With more nearly continuous heating, the effect of such gas penetration and oxidation is minimized, and the effect produced is more nearly that of the heat alone.

10. It is quite possible also, in a test of this character, that the composition of the surrounding gases may have a decided effect upon the amount of decomposition produced. Experiments by various investigators[2, 3] show a greatly decreased effect of heating when same is done either in vacuum or in hydrogen. Campbell and Glassford[3] quote a well known metallurgist who finds that "sudden variations in temperature or moisture content of the steam are probably most potent causes" of the effects of superheating.

Procedure in Conducting Tests

11. The furnace used in our Series *A* investigation was a Leeds and Northrup hump drawing furnace. The temperatures were read by a base-metal couple extending into the furnace at a height of about seven inches from the bottom. The temperatures were charted on an automatic recorder and were kept constant within a range of 5 degs. Fahr. plus or minus.

12. The base-metal couple was checked from time to time against a platinum couple using a portable Leeds & Northrup potentiometer. New material was used for each separate temperature run. The irons represented were all made in the cupola. The nickel and chromium additions were preheated and added to the ladle.

Heat Differences

13. In Series *A*, specimens were heated at test temperature for seven days, cooled, removed from furnace for brinell test; replaced in furnace, heated for seven days and again cooled and removed for brinell test; replaced in furnace and heated for remaining seven days, or a total of 500 hours, and again cooled.

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[3] Campbell and Glassford, *Constitution of Cast Iron and the Effects of Superheated Steam*, Proceedings International Assoc. for Treating Materials, 1912.

Determinations were then made for brinell hardness, combined carbon and tensile strength.

14. In our Series *B*, the 500 hours were a continuous heat at test temperature, the furnace then being cooled and samples tested for brinell hardness, combined carbon and tensile strength.

15. From preliminary tests made on several series we found no effect when heating up to and including 800 degs. Fahr. for a period of 500 hours. Accordingly, the reported tests begin at 800 degs. Fahr.

16. In the *A* series, bars were cast of various diameters to give tests on the same material with different degrees of hardness due to the various sections used.

Test Bar Differences

17. In the *B* series, bars were made 1 x 2 x 26 inches in length. These were broken transversely 24 in. between supports. All tensile bars were taken near the middle of the bar as cast and adjacent to the break when broken transversely. They were machined to a diameter of 0.505 in., threaded ends, and were pulled at a speed of ¼ in. per minute. All tensile specimens pulled at high temperature were heated slowly and held at test temperature for twenty minutes before test was made.

18. In the type of heating box used, the thermocouple is in contact with the center of the test specimen. All comparative physical and chemical determinations were made on material from comparative locations in the various specimens.

19. The test specimens in the Series *A* were cut into short lengths and these small pieces put into a container which was lowered into the furnace to a point near the base-metal couple leading to temperature recorder.

20. In the *B* series, the test bars 26 in. in length were set vertically in the furnace. As the furnace height was insufficient, it was necessary to build on a well-insulated extension about one foot in height. In order to equalize the heat in top and bottom, there was inserted a small auxiliary heater near the top of the furnace.

21. The temperature of the enlarged furnace was thoroughly explored by base-metal couples and found to be about 20 degs. Fahr. high at about half way from top to bottom. This was adjacent to point of application of load in transverse test. As the tensile bars were taken next to transverse break and all other

Table 1

(Series A)

CHEMICAL ANALYSES OF GRAY CAST IRON "AS CAST"

Type of Iron	Series No.	Size bar "As cast"	Tot. Carbon	Comb. Carbon	Graph. Carbon	Si	Sul	P	Mn	Ni	Cr
Symbol "HT": High-test iron—low-Carbon, high-Si, Nickel	5-6	2 in. Rd.	2.58	0.76	1.82	2.23	0.096	0.08	0.86	1.43	0.03
	28	2¼ in. Rd.	2.58	0.73	1.85	2.23	0.096	0.08	0.86	1.43	0.03
	9	3¼ in. Rd.	2.58	0.69	1.89	2.23	0.096	0.08	0.86	1.43	0.03
	11	1 in. x 2 in. x 26 in.	2.77	0.76	2.01	1.84	0.094	0.08	0.69	2.46	0.02
	8-10	1¼ in. Rd.	2.91	0.84	2.07	1.44	0.093	0.08	0.67	2.12	...
Symbol "A": High-carbon, low-Si	1	1 in. x 2 in. x 26 in.	3.66	0.76	2.90	1.24	0.075	0.43	0.55	0.02	0.02
	14-26	2 in. Rd.	3.66	0.71	2.95	1.29	0.121	0.21	0.78	....	....
	23	1¼ in. Rd.	3.46	0.65	2.81	1.44	0.101	0.29	0.68	...	...
Symb. "ANi": High-carbon, low-Si, Nickel	2	1 in. x 2 in. x 26 in.	3.61	0.73	2.88	1.12	0.082	0.19	0.65	0.90	0.02
Symbol "ACrNi": High-carbon, low and medium Si, Nickel, Chromium	3	1 in. x 2 in. x 26 in.	3.66	0.75	2.91	1.27	0.069	0.42	0.59	0.93	0.32
	4	1 in. x 2 in. x 26 in.	3.38	0.72	2.66	1.70	0.071	0.44	0.58	1.07	0.53

Table 2

(Series A)

COMBINED CARBON IN GRAY CAST IRON

(After Heating 500 Hours)

Type of Iron	Series No.	Size bar "As Cast"	Before heating	Heating temperatures, degs. Fahr. 800	850	900	950	1000	1050	1100
Symbol "HT": High-test iron—low-Carbon, high-Si, Nickel	5-6	2 in. Rd.	0.76	0.75	0.75	0.64	0.50	0.21	0.00	0.00
	28	2¼ in. Rd.	0.73	...	0.66	0.68	...	...	...	0.00
	9	3¼ in. Rd.	0.69	...	...	0.51	0.54	0.27	0.00	...
	11	1 in. x 2 in. x 26 in.	0.76	...	0.75	0.68	0.39	0.06	0.00	0.00
	8-10	1¼ in. Rd.	0.84	...	...	0.52	0.37	0.06	0.00	...
Symbol "A": High-Carbon, low-Si	1	1 in. x 2 in. x 26 in.	0.76	0.74	0.71	0.64	0.45	0.12	0.00	0.00
	14-26	2 in. Rd.	0.71	...	0.73	0.64	0.56	0.24	0.00	0.00
	23	1¼ in. Rd.	0.65	...	0.69	0.55	...	...	...	0.00
Symbol "ANi": High-Carbon, low-Si, Nickel	2	1 in. x 2 in. x 26 in.	0.73	0.72	0.70	0.61	0.26	0.07	0.00	0.00
Symb. "ACrNi": High-Carbon, low and med. Si, Nickel. Chromium	3	1 in. x 2 in. x 26 in.	0.75	0.76	0.75	0.70	0.63	0.45	0.28	0.16
	4	1 in. x 2 in. x 26 in.	0.72	0.71	0.71	0.68	0.63	0.53	0.24	0.22

tests were made at this point, the temperature of this area was used as recorded temperature of test run.

22. Most of our tests had been completed before this 20-degree difference in furnace temperature was discovered. Otherwise our tests at high temperature could all have been made at the temperature of the long-time heating. This would have avoided the two temperatures shown as heating and testing temperature in Table 11.

23. These transverse bars of Series *B* were not part of our original program, but were suggested to us by a member of our A. F. A. committee to determine whether the diminished load after heating was at all compensated for by an increased deflection. We did not find this to be the case.

Determination of Combined Carbon

24. The method of determining combined carbon was to determine the total carbon by combustion, the graphitic carbon gravimetrically and then to subtract the graphite from the total. The brinell and tensile tests and most of the carbon determinations were averages of two or more results.

25. It may be noted that the combined carbon is some-

Table 3

(Series A)

BRINELL HARDNESS OF GRAY CAST IRON

(After Heating 500 Hours)

Type of Iron	Series No.	Size bar "As Cast"	Before heating	Heating temperatures, degs. Fahr. 800	850	900	950	1000	1050	1100
"Symbol "HT": High-test iron—low-Carbon, high-Si, Nickel	5-6	2 in. Rd.	259	259	258	257	236	197	169	152
	28	2¼ in. Rd.	274	...	275	273	...	...	...	152
	9	3¼ in. Rd.	246	...	...	241	230	204	160	...
	11	1 in. x 2 in. x 26 in.	272	...	271	266	233	181	161	152
	8-10	1¼ in Rd.	269	...	...	250	224	159	146	...
"Symbol "A": High-Carbon, low-Si	1	1 in. x 2 in. x 26 in.	196	196	197	194	172	133	116	111
	14-26	2 in. Rd.	175	...	175	175	168	132	107	96
	23	1¼ in. Rd.	207	...	204	204	...	...	...	114
Symbol "ANi": High-Carbon, low-Si, Nickel	2	1 in. x 2 in. x 26 in.	199	200	196	191	159	125	117	110
Symbol "ACrNi": High-Carbon, low and medium Si, Nickel, Chromium	3	1 in. x 2 in. x 26 in.	220	220	221	218	209	181	165	152
	4	1 in. x 2 in. x 26 in.	244	241	245	241	228	217	195	183

times not quite in line with the other tests. The combined carbon can only be determined by difference and may show the sum of two errors. It would seem to us safer to rely upon the brinell hardness and tensile strength to indicate the changes produced by high temperatures.

Discussion of Results of Tests

Series A.

26. At 850 degs. Fahr. there was a very slight drop in combined carbon, with very little change in tensile strength and practically none in brinell hardness.

27. At 900 degs. Fahr. there was a decided drop in combined carbon in all but Series 3 and 4. The drop in these is much lower. There was not much change in hardness. There

Table 4

(Series A)

TENSILE STRENGTH OF GRAY CAST IRON

(After Heating 500 Hours)

Type of Iron	Series No.	Size bar "As Cast"	Before heating	Heating temperatures, degrees Fahr. 800	850	900	950	1000	1050	1100
Symbol "HT": High test Iron — low-carbon, high-Si, Nickel	5-6	2 in. Rd.	63,100	62,500	62,600	58,700	54,100	45,600	.....	.....
	28	2¼ in. Rd.	55,700	.....	.....	56,400	.....	.....	.....	38,100
	9	3¼ in. Rd.	54,500	.....	.....	54,200	53,100	48,200	38,700	.....
	11	1 in. x 2 in. x 26 in.	69,100	.....	64,000	64,800	56,200	48,000	43,000	41,500
	8-10	1¼ in. Rd.	56,200	.....	.....	52,400	45,100	.....	.....	.....
Symbol "A": High-Carbon, low-Si.	1	1 in. x 2 in. x 26 in.	32,350	32,750	32,350	32,850	29,150	23,350	20,700	20,900
	14-26	2 in. Rd.	29,100	.....	29,000	28,800	26,000	21,750	19,050	17,200
	23	1¼ in. Rd.	36,050	.....	.....	33,000	.....	.....	.....	21,900
Symbol "ANi": High-Carbon, low-Si, Nickel	2	1 in. x 2 in. x 26 in.	35,500	34,600	35,100	34,650	28,500	23,550	22,200	20,550
Symbol "ACrNi": High-Carbon, low and med. Si. — Nickel — Chromium	3	1 in. x 2 in. x 26 in.	37,300	37,000	37,550	35,250	36,950	29,500	26,950	24,250
	4	1 in. x 2 in. x 26 in.	42,900	42,550	42,200	44,000	44,450	41,800	36,750	33,600

was considerable loss in tensile strength, but less in those specimens containing chromium.

28. At 950 degs. Fahr. the action was continued with a loss in strength in all, but much less in Series 3 and 4, which contain chromium.

29. At 1000 and 1050 degs. Fahr. the softening and weakening action was further continued, and at 1050 degs. there was found freedom from combined carbon in all but the series containing chromium.

Table 5

(Series A)

BRINELL HARDNESS OF GRAY CAST IRON

(After Heating 168 Hours, 336 Hours, and 500 Hours)

Type of Iron	Series No.	Bar Size	Hardness before heating	Temp. degs. Fahr.	Hardness after heating 168 Hrs.	336 Hrs.	500 Hrs.
Symbol "HT": High-test iron—low-Carbon, high-Si, Nickel	5-6	2 in. Rd. x 15 in.	259	800	259	260	259
				850	255	255	258
				900	260	255	257
				950	259	251	236
				1,000	236	223	197
				1,050	210	182	169
				1,100	163	156	152
	28	2¼ in. Rd. x 15 in.	274	800	...	...	...
				850	...	...	...
				900	277	277	273
				950	...	...	...
				1,000	...	...	...
				1,050	...	...	...
				1,100	165	157	152
	9	3¼ in. Rd. x 15 in.	246	800	...	...	...
				850	...	...	...
				900	248	241	241
				950	239	238	230
				1,000	235	217	204
				1,050	196	172	160
				1,100	...	...	...
	11	1 in. x 2 in. x 26 in.	272	800	...	...	...
				850	...	...	...
				900	277	269	266
				950	255	248	233
				1,000	238	202	181
				1,050	174	163	161
				1,100	159	157	152
	9-10	1¼ in. Rd. x 15 in.	269	800	...	...	...
				850	...	...	...
				900	269	259	250
				950	248	234	224
				1,000	202	172	159
				1,050	156	149	146
				1,100	...	...	...

(Table 5 continued on page 834)

Table 5—*(Concluded)*

(Series A)

BRINELL HARDNESS OF GRAY CAST IRON

(After Heating 168 Hours, 336 Hours, and 500 Hours)

Type of Iron	Series No.	Bar Size	Hardness before heating	Temp. degs. Fahr.	Hardness after heating 168 Hrs.	336 Hrs.	500 Hrs.
Symbol "A": High - Carbon, low-Si.	1	1 in. x 2 in. x 26 in.	196	800	196	196	196
				850	196	196	197
				900	196	194	194
				950	190	177	172
				1,000	159	142	133
				1,050	130	118	116
				1,100	117	115	111
	14-26	2 in. Rd. x 15 in.	175	800	...	...	...
				850	...	...	...
				900	175	175	175
				950	163	172	168
				1,000	156	137	132
				1,050	133	112	107
				1,100	114	97	96
	23	1 in. x 2 in. x 26 in.	207	800	...	...	...
				850	...	...	...
				900	207	197	204
				950	...	...	...
				1,000	...	...	...
				1,050	...	...	...
				1,100	117	115	114
Symbol "ANi": High - Carbon, low-Si, Nickel	2	1 in. x 2 in. x 26 in.	199	800	197	200	200
				850	198	198	196
				900	198	192	191
				950	190	166	159
				1,000	153	134	125
				1,050	125	118	117
				1,100	115	109	110
Symbol "ACrNi" High - Carbon, low and med. Si, Nickel, Chromium	3	1 in. x 2 in. x 26 in.	220	800	220	217	220
				850	217	217	221
				900	223	220	218
				950	220	214	209
				1,000	199	187	181
				1,050	183	175	165
				1,100	170	156	152
	4	1 in. x 2 in. x 26 in.	244	800	241	244	241
				850	241	243	245
				900	246	245	241
				950	241	238	228
				1,000	228	226	217
				1,050	212	204	195
				1,100	207	190	183

Series B.

30. At 870 degs. Fahr. there was a drop in combined carbon, with no change in brinell. There were only slight changes in transverse and tensile strengths.

31. At 920 degs. Fahr. there was a decided drop in combined carbon and a drop in brinell in Series 29 and 31. There was also a loss of transverse and tensile strength in the chromium-free specimen.

32. At 970 degs. Fahr. there was a great loss in brinell hardness, combined carbon and tensile and transverse strength in the Series 31 and 29. The Series 30 and 32 containing chromium showed much less loss.

33. At 1020 degs. Fahr. both Series 31 and 29 showed entire freedom from combined carbon.

34. As the combined carbon diminished, the strength and hardness of all the series continued to fall off up to the maximum temperature of the test.

35. The transverse bars heated at high temperature seemed to average a little lower in deflection, which checks our results obtained in 1922. The surface of these bars may have been slightly affected by the hot gases; if we repeat this experiment, we will machine some of the specimens to determine whether any increased deflection might be so obtained.

36. In Series *B*, in addition to making tensile tests at room temperature of the annealed material, tensile tests were also made at the temperature at which these bars had been previously heated. The purpose of this test was to determine the tensile strength of any iron in service at a given temperature after a 500-hour hold. Tensile tests were also made at elevated temperatures of the unannealed material (see Series *B*, Tables 10, 11 and 12).

Tests Results

37. It is to be noted that Series 31 , Table 11, broke in its "as cast" and untreated condition at 49,900 lbs. per sq. in. This material lost approximately 25 per cent tensile value on heating 500 hours at 920 degs. Fahr. and pulling at a temperature of 900 degs. Fahr., while heating 500 hours at 1020 degs. Fahr. and pulling at 1000 degs. caused a loss of nearly 57 per cent of its tensile strength. Series 29 lost 22 per cent after heating at 920 degs. Fahr. and 54 per cent after heating at 1020 degs.

Table 6
(Series B)
CHEMICAL ANALYSIS OF GRAY CAST IRON "AS CAST"

Type of Iron	Series No.	Size bar "As cast"	Tot. Carbon	Comb. Carbon	Graph. Carbon	Si	Sul	P	Mn	Ni	Cr
Symbol "HT": High-test Iron — low-Carbon, high-Si, Nickel	31	1 in. x 2 in. x 26 in.	2.96	0.73	2.23	2.53	0.113	0.06	0.78	0.96	0.02
Symbol "HTCr": Low-Carbon, high-Si, Chromium	32	1 in. x 2 in. x 26 in.	2.67	0.79	1.88	2.39	0.090	0.07	0.67	0.76	0.45
Symbol "A": High-Carbon, low-Si	29	1 in. x 2 in. x 26 in.	3.63	0.73	2.90	1.15	0.091	0.17	0.54	0.03	0.03
Symb. "ACr": High-Carbon, low-Si, Chromium	30	1 in. x 2 in. x 26 in.	3.46	0.87	2.59	1.36	0.085	0.39	0.68	0.015	0.54

Table 7
(Series B)
COMBINED CARBON IN GRAY CAST IRON
(After Heating 500 Hours)

Type of Iron	Series No.	Size of bar "As Cast"	Before heating	Heating temperatures, degs. Fahr. 870	920	970	1020	1120
Symbol "HT": High-test iron—low-Carbon, high-Si, Nickel	31	1 in. x 2 in. x 26 in.	0.73	0.67	0.46	0.10	0.00	0.00
Symbol "HTCr": Low-Carbon, high-Si, Nickel, Chromium	32	1 in. x 2 in. x 26 in.	0.79	0.76	0.68	0.57	0.47	0.16
Symbol "A": High-Carbon, low-Si	29	1 in. x 2 in. x 26 in.	0.73	0.61	0.44	0.08	0.00	0.00
Symb. "ACr": High-Carbon, low-Si, Chromium	30	1 in. x 2 in. x 26 in.	0.87	0.83	0.72	0.70	0.68	0.33

Table 8

(Series B)

BRINELL HARDNESS OF GRAY CAST IRON

(After Heating 500 Hours)

Type of Iron	Series No.	Size of bar "As Cast"	Before heating	Heating temperatures, degs. Fahr. 870	920	970	1020	1120
Symbol "HT": High-test Iron — low-Carbon, high-Si, Nickel	31	1 in. x 2 in. x 26 in.	234	235	217	171	146	145
Symbol "HTCr": Low-Carbon, high-Si, Nickel, Chromium	32	1 in. x 2 in. x 26 in.	267	269	269	252	223	191
Symbol "A": High-Carbon, low-Si	29	1 in. x 2 in. x 26 in.	184	187	169	138	116	113
Symb. "ACr": High-Carbon, low-Si, Chromium	30	1 in. x 2 in. x 26 in.	227	232	223	221	207	178

Table 9

(Series B)

TRANSVERSE BREAKING LOAD AND DEFLECTION OF GRAY CAST IRON

Broken Between 24 Inch Supports

(After Heating 500 Hours)

Type of Iron	Series No.	Size of bar "As Cast"		Before heating	Heating temperatures, degrees Fahr. 870	920	970	1020	1120
Symbol "HT": High-test iron —low-Carbon, high-Si, Nickel	31	1 in. x 2 in. x 26 in.	Load	3,660	3,520	3,350	2,990	2,760	2,570
			Deflec.	0.48	0.47	0.46	0.47	0.44	0.43
Symbol "HTCr": Low-Carbon, high-Si, Nickel, Chromium	32	1 in. x 2 in. x 26 in.	Load	4,000	....	3,700	....	3,760	3,400
			Deflec.	0.42	....	0.37	....	0.38	0.42
Symbol "A": High-Carbon, low-Si	29	1 in. x 2 in. x 26 in.	Load	2,660	2,630	2,470	2,190	2,050	1,870
			Deflec.	0.53	0.51	0.45	0.45	0.48	0.43
Symbol "ACr": High-Carbon, low-Si, Chromium	30	1 in. x 2 in. x 26 in.	Load	3,110	3,070	3,080	3,220	3,150	2,720
			Deflec.	0.46	0.42	0.47	0.50	0.48	0.55

Table 10

(Series B)

TENSILE STRENGTH OF GRAY CAST IRON

(After Heating 500 Hours, Tested at Room Temperature)

Type of Iron	Series No.	Size of bar "As Cast"	Before heating	Heating temperatures, degs. Fahr. 870	920	970	1020	1120
Symbol "HT": High-test Iron — low-Carbon, high-Si, Nickel	31	1 in. x 2 in. x 26 in.	49,900	50,900	47,350	37,750	33,300	31,500
Symbol "HTCr": Low-Carbon, high-Si, Nickel, Chromium	32	1 in. x 2 in. x 26 in.	62,700	65,600	62,600	61,000	57,200	48,200
Symbol "A": High-Carbon, low-Si	29	1 in. x 2 in. x 26 in.	32,800	32,700	30,700	24,600	21,900	20,000
Symb. "ACr": High-Carbon, low-Si, Chromium	30	1 in. x 2 in. x 26 in.	41,900	41,800	41,700	39,200	38,900	32,000

Table 11

(Series B)

TENSILE STRENGTH OF GRAY CAST IRON

(After Heating 500 Hours, Tested at Elevated Temperature)

Type of Iron	Series No.	Size of bar "As Cast"	Before heating	Heating temperatures, degs. Fahr. 870 Testing temperatures, degs. Fahr. 850	920 900	970 950	1020 1000	1120 1100
Symbol "HT": High-test iron—low-Carbon, high-Si, Nickel	31	1 in. x 2 in. x 26 in.	49,900	45,400	37,600	28,550	21,600	17,100
Symbol "HTCr": Low-Carbon, high-Si, Nickel, Chromium	32	1 in. x 2 in. x 26 in.	62,700	60,400	54,500	49,300	40,100	25,700
Symbol "A": High-Carbon, low-Si	29	1 in. x 2 in. x 26 in.	32,800	29,900	25,400	19,700	15,000	12,650
Symb. "ACr": High-Carbon, low-Si, Chromium	30	1 in. x 2 in. x 26 in.	41,900	40,000	36,450	34,700	28,150	19,800

38. In the Series 30 and 32, both containing chromium, the loss was not so great. Series 32 lost 13 per cent after heating at 920 degs. Fahr. and 36 per cent at 1020 degs. Series 30 lost 13 per cent at 920 degs. Fahr. and 32 per cent at 1020 degs. Losses of this magnitude must be taken into consideration when designing parts to operate at elevated temperatures.

39. A number of tests were made of an iron with silicon 2.23 and carbon 3.50 per cent. As far as these tests were conducted, they seemed to follow the general laws as developed by the other irons, the strength falling to 11,800 at room temperature after heating 500 hours at 1120 degs. Fahr. Inasmuch as this iron was not under consideration for high temperature service, the series was not completed.

Microscopic Study

40. We are showing herewith seven series of photomicrographs (Figs. 10-16, incl.) taken before and after various heating operations. In Series 1, 2 and 11 (Figs. 10, 11, 12, 13) it will

Table 12

(Series B)

TENSILE STRENGTH OF GRAY CAST IRON "AS CAST"

(Tested at Elevated Temperatures)

Type of Iron	Series No.	Size of bar "As Cast"	Tested at room Temps.	Testing temperatures, degs. Fahr. 850	900	950	1000	1100
Symbol "HT": High-test iron—low-Carbon, high-Si, Nickel	31	1 in. x 2 in. x 26 in.	49,900	45,500	43,150	40,600	37,000	28,300
Symbol "HTCr": Low-Carbon, high-Si, Nickel, Chromium	32	1 in. x 2 in. x 26 in.	62,700	60,650	56,300	55,500	50,700	38,800
Symbol "A": High-Carbon, low-Si	29	1 in. x 2 in. x 26 in.	32,800	30,800	29,100	27,200	24,800	19,800
Symb. "ACr": High-Carbon, low-Si, Chromium	30	1 in. x 2 in. x 26 in.	41,900	40,200	38,400	36,600	34,200	25,800

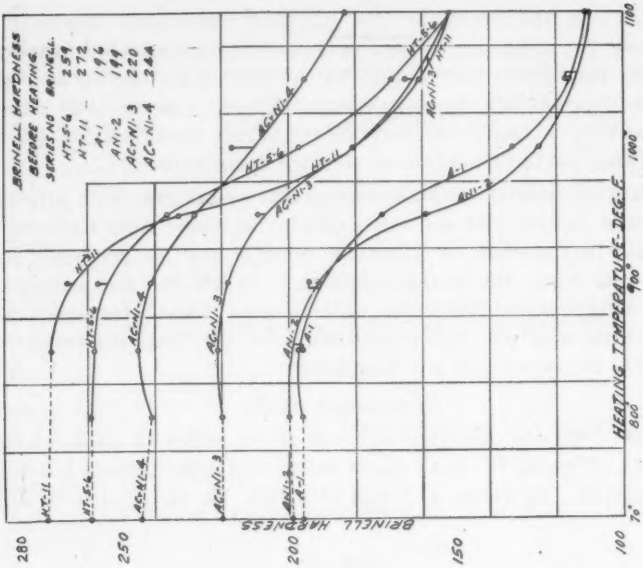

FIG. 2—BRINELL HARDNESS AFTER 500 HOURS HEATING. (SERIES A)

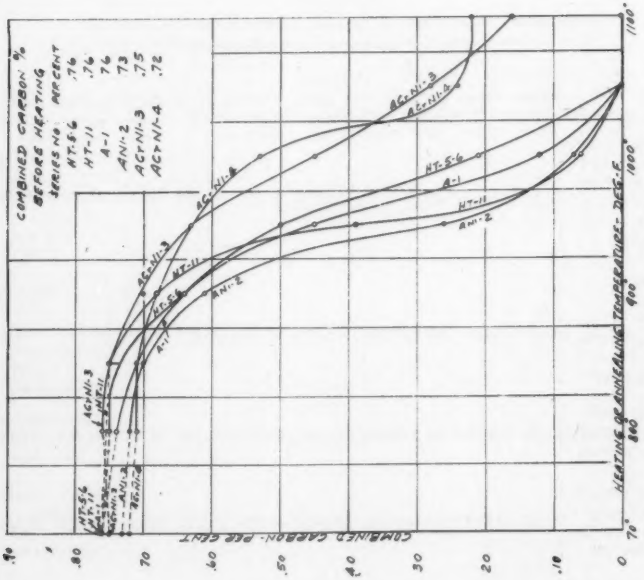

FIG. 1—EFFECT OF HEATING FOR 500 HOURS ON COMBINED CARBON. (SERIES A)

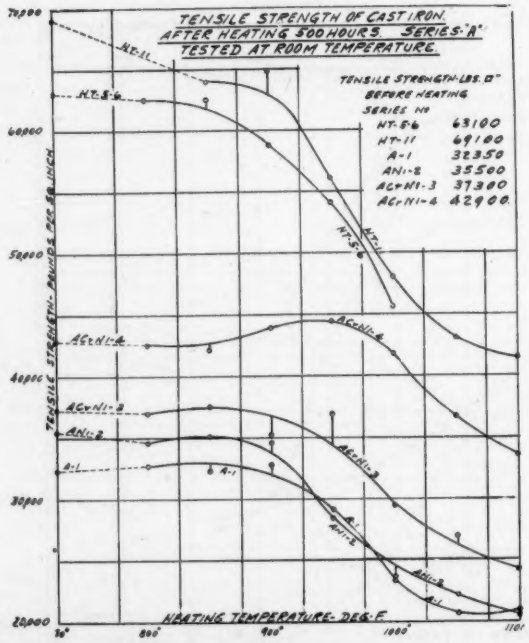

FIG. 3—TENSILE STRENGTH AT ROOM TEMPERATURES AFTER 500 HOURS HEATING. (SERIES A)

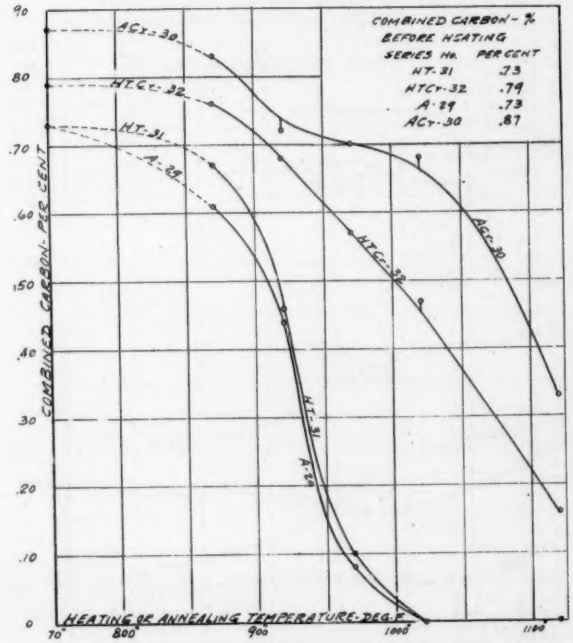

FIG. 4—EFFECT OF HEATING FOR 500 HOURS ON COMBINED CARBON. (SERIES B)

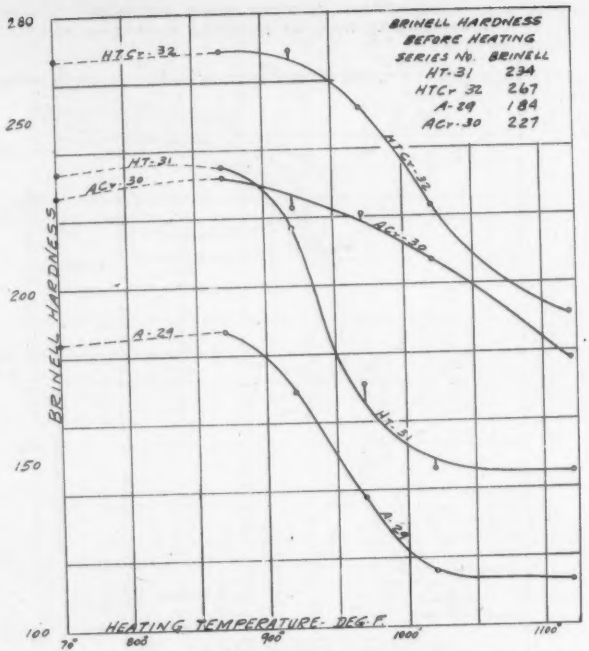

FIG. 5—BRINELL HARDNESS AFTER 500 HOURS HEATING. (SERIES B)

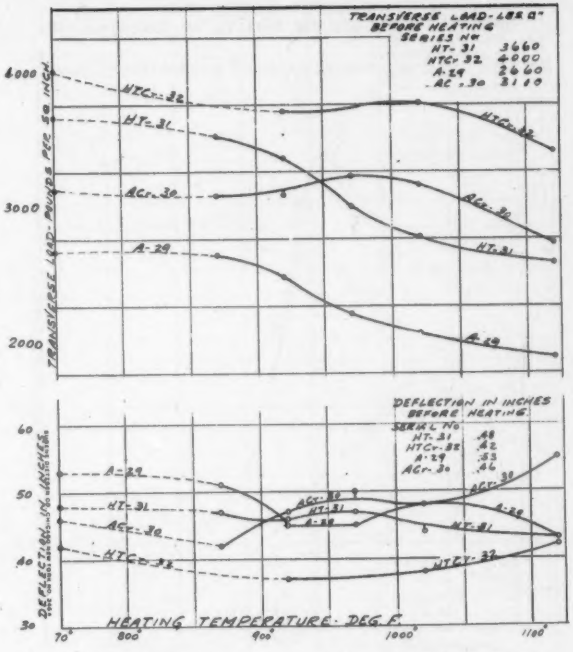

FIG. 6—TRANSVERSE BREAKING LOAD AND DEFLECTION AFTER HEATING FOR 500 HOURS. (SERIES B)

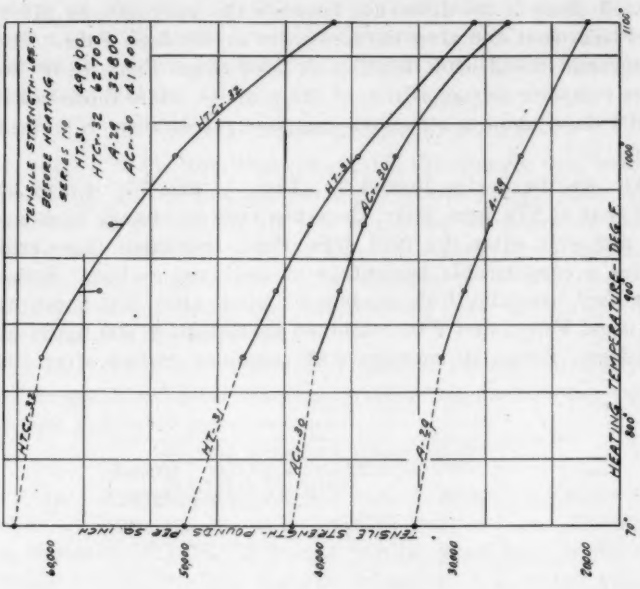

Fig. 8—Tensile Strength "As Cast" But Tested at Elevated Temperatures. (Series B)

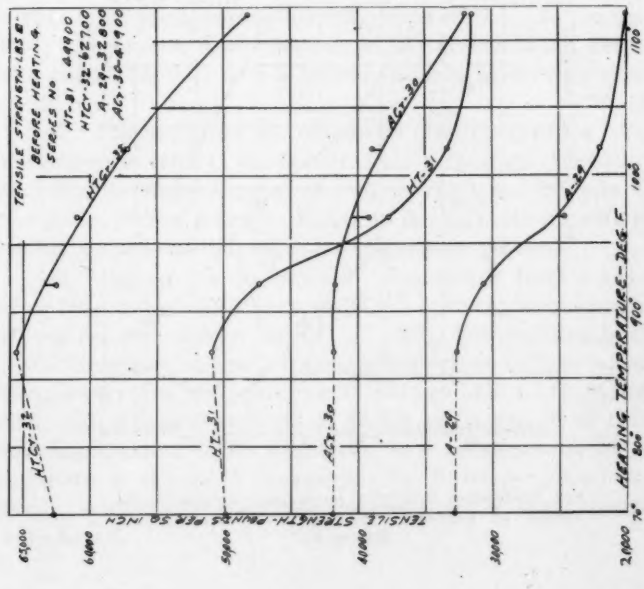

Fig. 7—Tensile Strength at Room Temperatures After Heating for 500 Hours. (Series B)

be noted there is no difference between the micrographs taken before treatment and after the treatment at 850 degs. Fahr. The micrographs taken after heating at 1000 degs. Fahr. show an almost complete decomposition of the pearlite, while those taken at 1100 degs. show a structure completely free from combined carbon.

41. In the Series 30 and 32 (Figs. 14 and 15) it will be noted that at 870 degs. Fahr. there has been no change in structure, and even after the 1020 degs. Fahr. treatment there still remains a considerable percentage of combined carbon. Series 32, in fact, contains 0.47 combined carbon after 500 hours at 1020 degs. Fahr., and 0.16 combined carbon after 500 hours at 1120 degs. Series 30 contains 0.68 combined carbon after 500

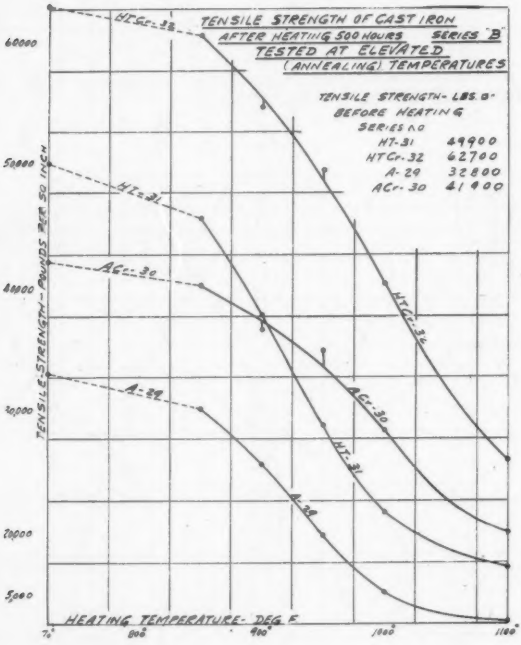

FIG. 9—TENSILE STRENGTH AFTER HEATING 500 HOURS. TESTED AT ELEVATED (ANNEALING) TEMPERATURES. (SERIES B)

hours at 1020 degs. Fahr., and 0.33 combined carbon after 500 hours at 1120 degs. These two series are the ones containing chromium, which apparently accounts for this holding up at high temperature.

Progressive Disintegration of Eutectoid

42. The photomicrographs reveal the changes that were produced by this prolonged heating. Starting out with typical pearlitic structures in all the irons, the micrographs show a progressive disintegration of this eutectoid into graphite and ferrite. The graphite apparently migrates to the already-existing graphite plates, while the ferrite areas grow as the annealing temperatures are increased.

43. The lessening pearlite present is usually found adjacent to the graphite flakes. These graphite flakes have become swollen in size and fuzzy in appearance.

Data on Liner Castings

44. It might be interesting to note several instances of the effect of long-time operation at high temperature. Micrograph *A*, Series *C* (Fig. 16), is from a marine diesel liner of European manufacture. It had been in operation four years and was removed on account of wear. The analysis shows: Graphitic carbon 2.10; combined carbon 0.76; total carbon 2.86; manganese 0.36; phosphorus 0.56; sulphur 0.126; silicon 2.21; chromium 0.46 and nickel 0.73, with a tensile strength of 29,300 and brinell of 202.

45. The structure was originally lamellar pearlite. Part of the cementite veins in the pearlite have become spherodized, probably due to temperature of operation. This was in spite of the chromium present and may be due to the high silicon. We regret having no information as to its original properties.

46. Micrograph *B*, Series *C* (Fig. 16), is from a gas liner after four and one-half years or 37,879 hours of actual operation. It was not removed on account of wear. The analysis is as follows: Graphitic carbon 2.42; combined carbon 0.73; total carbon 3.15; manganese 0.86; phosphorus 0.34; sulphur 0.115 and silicon 0.96, with a tensile strength of 34,250 and a brinell of 197. At the magnification of 500 diameters, there appears to be no breaking down or change of the pearlite due to temperature of operation. On examination at 2000 diameters, traces of spherodization were found.

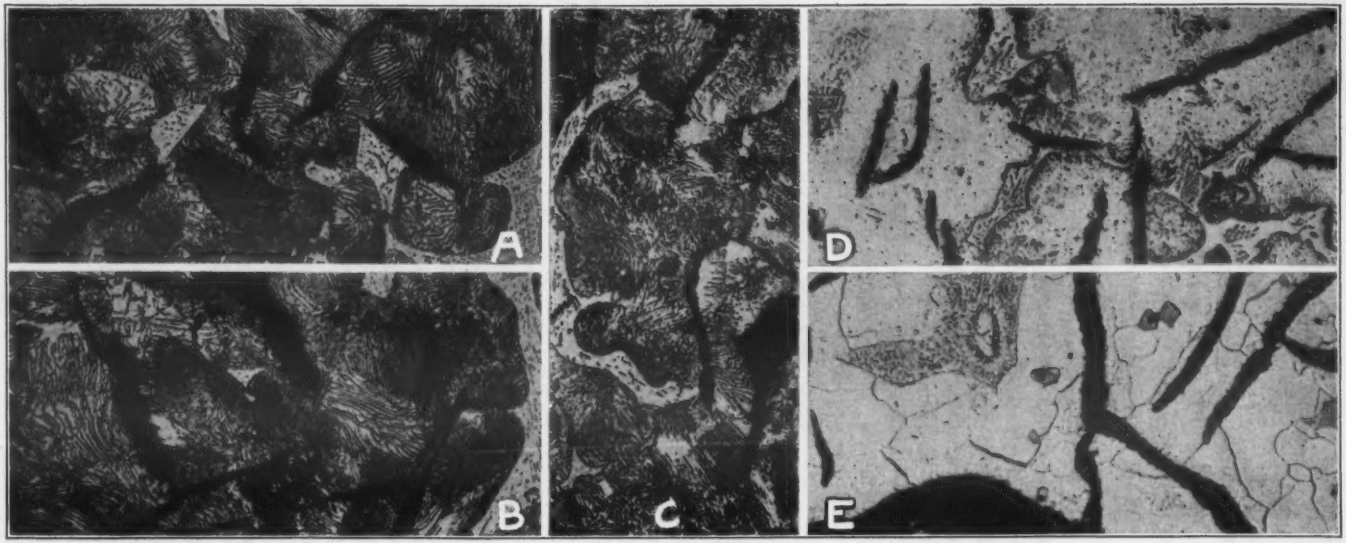

FIG. 10—(SERIES A-1) "A" IRON: HIGH CARBON, LOW SILICON. *A*—"AS CAST" OR UNANNEALED. 500 X. COMBINED CARBON 0.76 PER CENT.
B—ANNEALED 850 DEGS. FAHR. 500 X. COMBINED CARBON 0.71 PER CENT.
C—ANNEALED 950 DEGS. FAHR. 500 X. COMBINED CARBON 0.45 PER CENT.
D—ANNEALED 1000 DEGS. FAHR. 500 X. COMBINED CARBON 0.12 PER CENT.
E—ANNEALED 1100 DEGS. FAHR. 500 X. NO COMBINED CARBON.

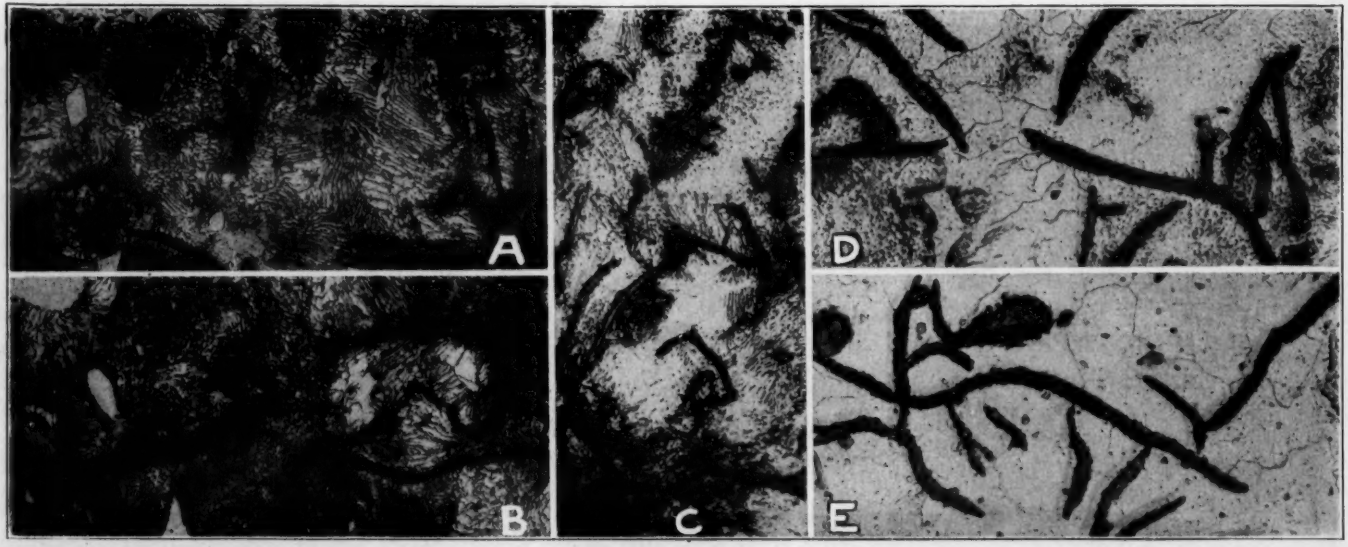

FIG. 11—(SERIES A-2) "ANi" IRON: HIGH CARBON, LOW SILICON, NICKEL. *A*—"AS CAST" OR UNANNEALED. 500 X. COMBINED CARBON 0.73 PER CENT.
B—ANNEALED 850 DEGS. FAHR. 500 X. COMBINED CARBON 0.70 PER CENT.
C—ANNEALED 950 DEGS. FAHR. 500 X. COMBINED CARBON 0.26 PER CENT.
D—ANNEALED 1000 DEGS. FAHR. 500 X. COMBINED CARBON 0.07 PER CENT.
E—ANNEALED 1100 DEGS. FAHR. 500 X. NO COMBINED CARBON.

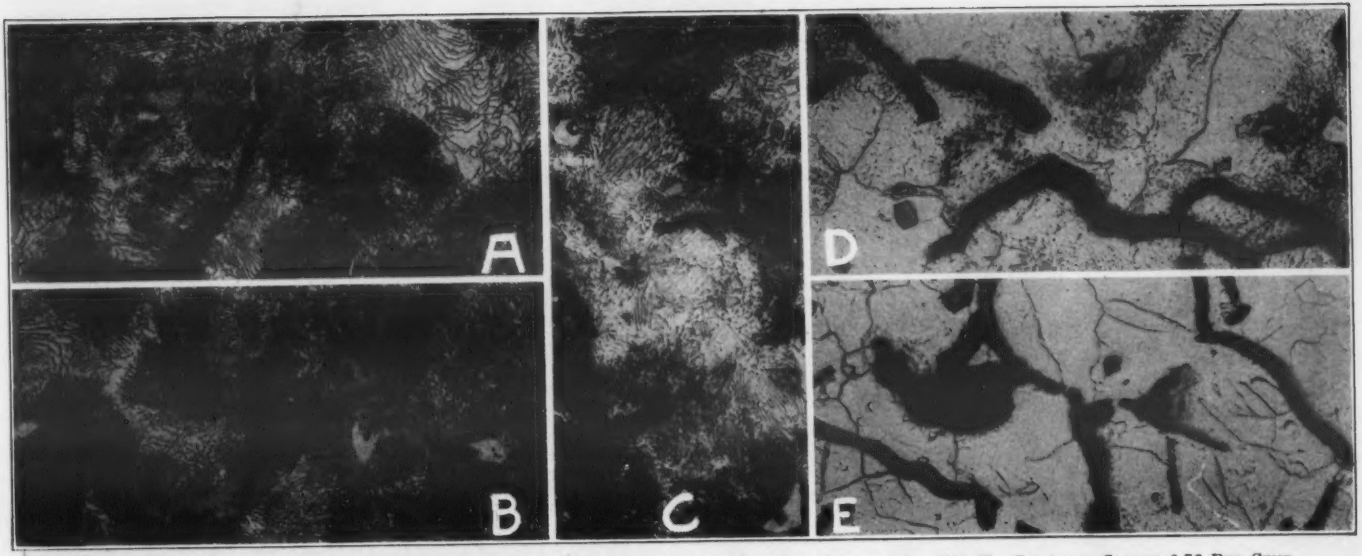

FIG. 12—(SERIES A-11) HIGH-TEST IRON: LOW CARBON, HIGH SILICON, NICKEL. *A*—"AS CAST" OR UNANNEALED. 500 X. COMBINED CARBON 0.76 PER CENT.
B—ANNEALED 850 DEGS. FAHR. 500 X. COMBINED CARBON 0.75 PER CENT.
C—ANNEALED 950 DEGS. FAHR. 500 X. COMBINED CARBON 0.39 PER CENT.
D—ANNEALED 1000 DEGS. FAHR. 500 X. COMBINED CARBON 0.06 PER CENT.
E—ANNEALED 1100 DEGS. FAHR. 500 X. NO COMBINED CARBON.

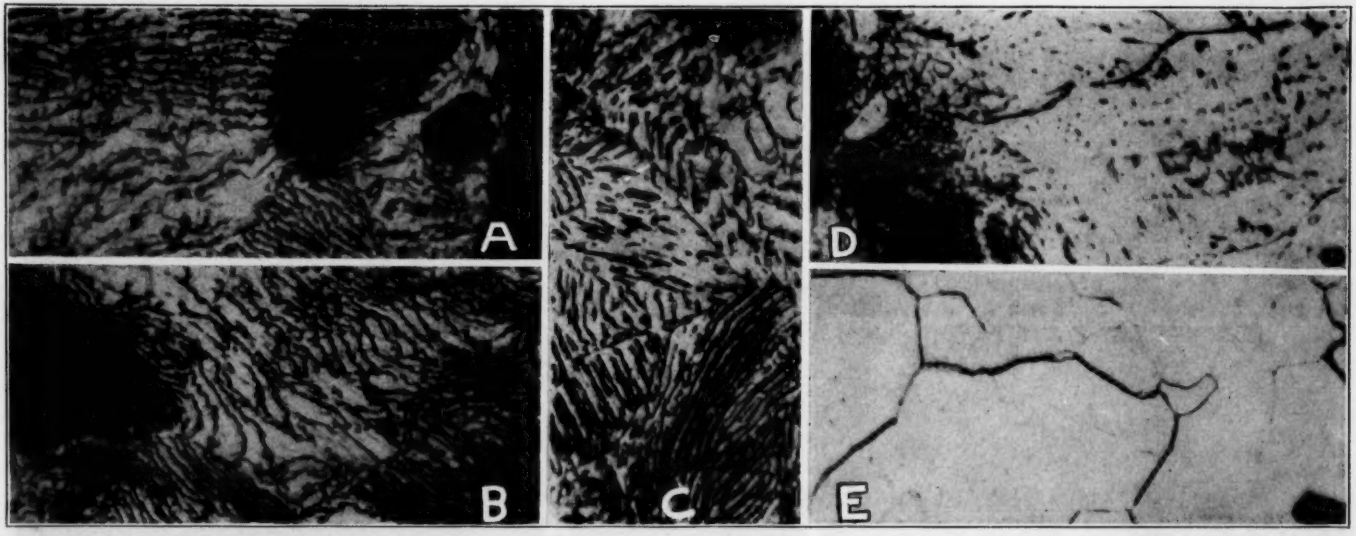

FIG. 13—(SERIES A-11) HIGH-TEST IRON : LOW CARBON, HIGH SILICON, NICKEL. *A*—"AS CAST" OR UNANNEALED. 2000 X. COMBINED CARBON 0.76 PER CENT.
B—ANNEALED 850 DEGS. FAHR. 2000 X. COMBINED CARBON 0.75 PER CENT.
C—ANNEALED 950 DEGS. FAHR. 2000 X. COMBINED CARBON 0.39 PER CENT.
D—ANNEALED 1000 DEGS. FAHR. 2000 X. COMBINED CARBON 0.06 PER CENT.
E—ANNEALED 1100 DEGS. FAHR. 2000 X, NO COMBINED CARBON.

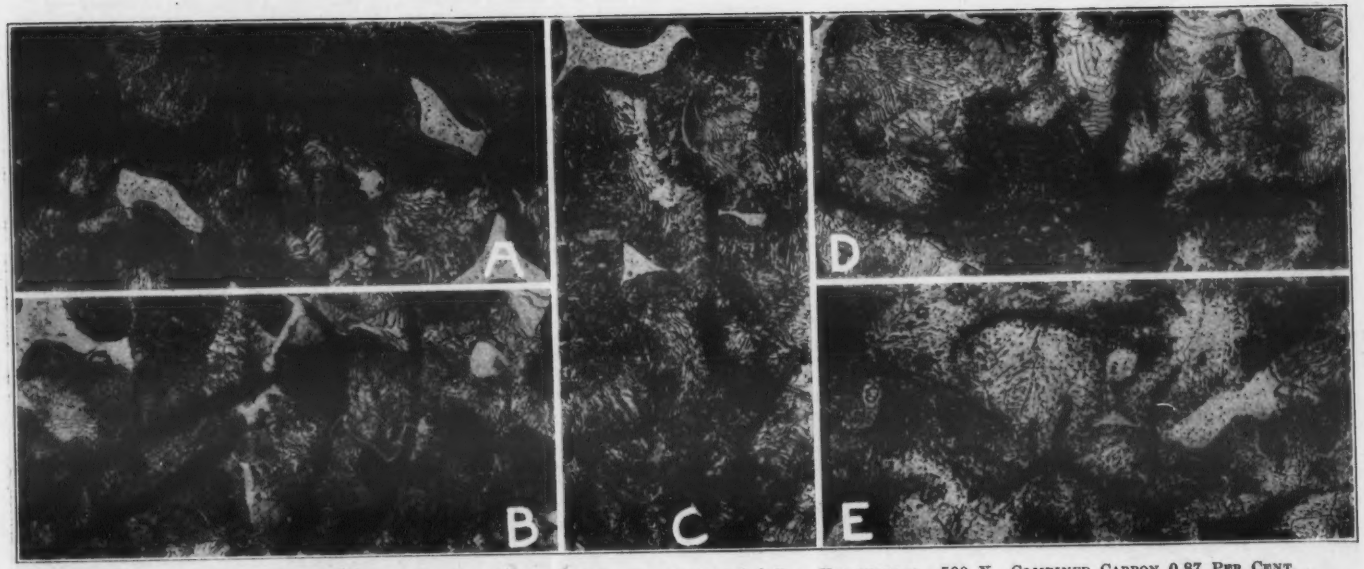

FIG. 14—(SERIES B-30) "ACR" IRON: HIGH CARBON, LOW SILICON, CHROMIUM. *A*—"AS CAST" OR UNANNEALED. 500 X. COMBINED CARBON 0.87 PER CENT.
B—ANNEALED 870 DEGS. FAHR. 500 X. COMBINED CARBON 0.83 PER CENT.
C—ANNEALED 970 DEGS. FAHR. 500 X. COMBINED CARBON 0.70 PER CENT.
D—ANNEALED 1020 DEGS. FAHR. 500 X. COMBINED CARBON 0.68 PER CENT.
E—ANNEALED 1120 DEGS. FAHR. 500 X. COMBINED CARBON 0.33 PER CENT.

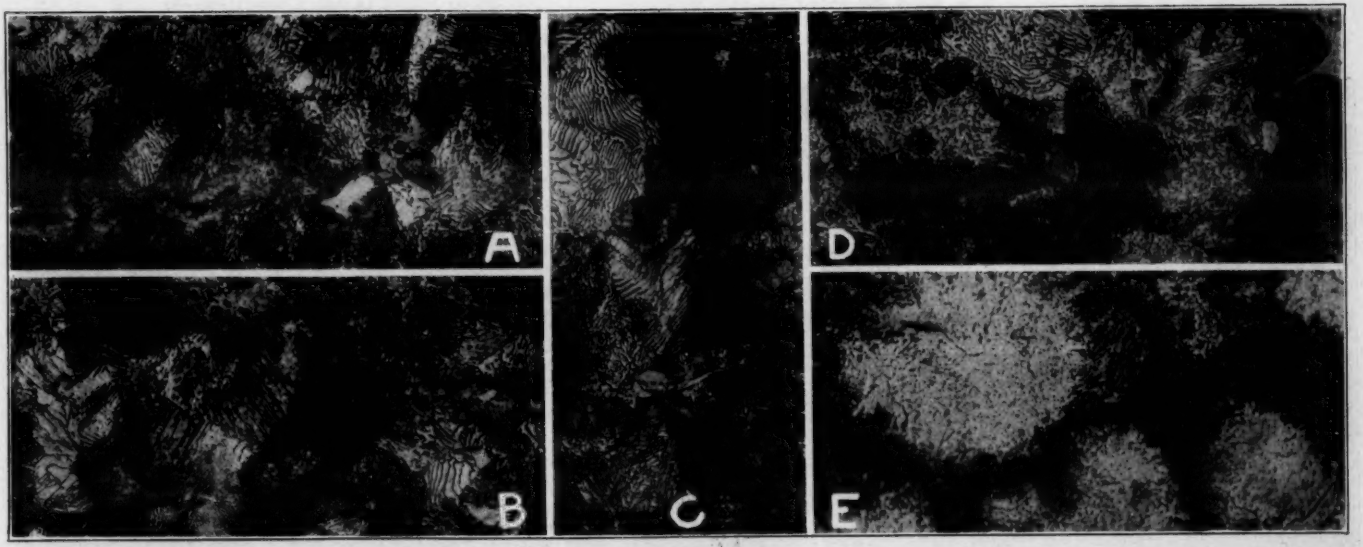

FIG. 15—(SERIES B-32) HIGH-TEST IRON CONTAINING CHROMIUM: LOW CARBON, HIGH SILICON, CHROMIUM. *A*—"AS CAST" OR UNANNEALED. 500 X. COMBINED CARBON 0.79 PER CENT.
B—ANNEALED 870 DEGS. FAHR. 500 X. COMBINED CARBON 0.76 PER CENT.
C—ANNEALED 970 DEGS. FAHR. 500 X. COMBINED CARBON 0.57 PER CENT.
D—ANNEALED 1020 DEGS. FAHR. 500 X. COMBINED CARBON 0.47 PER CENT.
E—ANNEALED 1120 DEGS FAHR. 500 X. COMBINED CARBON 0.16 PER CENT.

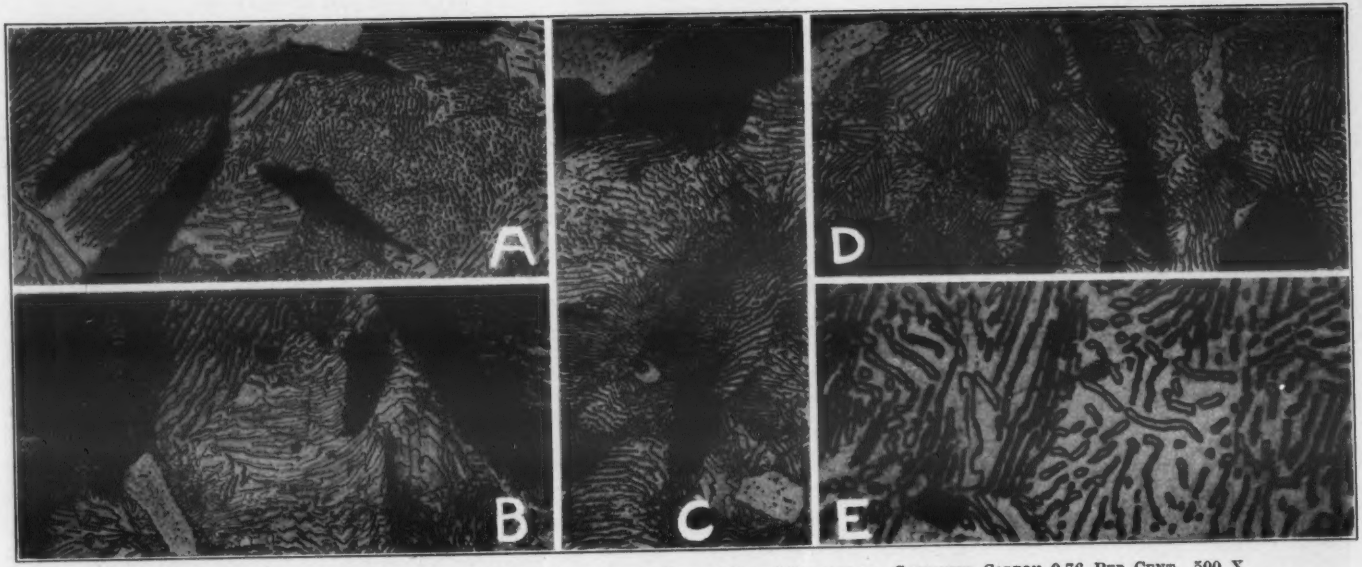

FIG. 16—(SERIES C) LINER CASTINGS. *A*—MARINE DIESEL LINER AFTER 4 YEARS' OPERATION. COMBINED CARBON 0.76 PER CENT. 500 X.
B—GAS LINER. "AS CAST." COMBINED CARBON 0.79 PER CENT. 500 X.
C—GAS LINER AFTER 4½ YEARS' OPERATION. COMBINED CARBON 0.73 PER CENT. 500 X.
D—GAS LINER AFTER 17 YEARS' OPERATION. COMBINED CARBON 0.80 PER CENT. 500 X.
E—SAME AS *D*, BUT 2000 X.

47. We made no micrograph of this liner before installation, but micrograph *C*, Series *C* (Fig. 16), shows an iron from another liner of the same section and quite similar composition. This analysis is: Graphitic carbon 2.33; combined carbon 0.79; total carbon 3.12; manganese 0.82; phosphorus 0.34; sulphur 0.112 and silicon 0.92, with a tensile strength of 45,500 and a brinell of 226. The test specimens were cut from full-sized prolongation of liner.

48. Micrograph *D*, Series *C* (Fig. 16), is from a gas liner after 17 years' service. The analysis is as follows: Graphitic carbon 2.58; combined carbon 0.80; total carbon 3.38; manganese 0.58; phosphorus 0.45; sulphur 0.108 and silicon 0.75, with a tensile strength of 32,600 and a brinell of 177. The structure at 500 diameters shows traces of spheroidized cementite, and it is apparent to the examiner that a slight softening has evidently taken place.

49. There was some wear of this liner, but it was removed for other causes. We have estimates of the temperature of operation of the above liners but no definite tests. The spherodization of the cementite veins in the above structures is most interesting, and in these few cases is in proportion to the amount of wear shown.

50. The test specimens were made with threaded ends, and the tensile strength given of our liners is an average of two results.

Conclusions

51. We are making only the most general conclusions and would caution against making too many definite deductions upon the comparatively few tests which thus far have been made.

52. It would seem, however, that high silicon materially accelerates the decomposition of the pearlite, and that nickel does the same, although not to the same extent. Low silicon and low carbon with finely divided graphite flakes tend to delay this action. Chromium decidedly increases tensile strength at room temperature and delays decomposition of pearlite. It also operates to hold up the strength at high temperatures.

53. The tests are rather instructive in showing a low tensile strength at elevated temperatures. The best showing was made

by the series containing chromium. It would seem that heat-resistant iron cannot be made by running on low carbon with high silicon and nickel to promote fluidity and machinability, but that a low-silicon low-carbon iron is much to be preferred and that the addition of even 0.5 per cent chromium greatly increases the stability of the carbide and the strength at high temperature.

54. In many foundries in Europe an iron with less than one per cent silicon and about three per cent carbon is being made. This iron, when poured into small castings, would ordinarily be too hard to machine. Their practice, however, is to pour this same metal into molds which are preheated to a high degree. This produces a much slower cooling and leaves the castings in a machinable condition. A pearlitic structure is desired.

55. Castings of this type are often used where a minimum growth is essential. All the conditions favoring a low growth are present, and these are probably as free from growth as any gray iron castings can be. It might be of interest to note, however, that all our liners above described as Series *C* were made with an entirely pearlitic structure but not by the hot-mold process.

56. It should be remembered that there is nothing in these tests, even at 1120 degs. Fahr., which would indicate that the maximum effect of heat at that particular temperature had been reached.

57. The brinell tests in Series *A*, Table 5, show that when running at these temperatures there is a progressive loss of brinell from one week to the next. On several series also there is a continued loss in tensile strength and brinell hardness, even after the entire decomposition of the carbide has been accomplished. It is quite possible that a longer time at the higher temperatures would both soften and weaken all the material tested. A second 500 hours heating at 950 degs. Fahr. of Series *B* bars caused slight further losses in both the chrome-free series, but not in either of the two series of bars which contain chromium.

Suggests Work on Pearlite Decomposition

58. A series of experiments to determine the equivalent or the quantitative effect or influence of the various elements on

this decomposition of pearlite, and its relation to growth, would be most interesting and instructive. It is a question that the makers of cast iron must some time be in a position to answer.

DISCUSSION

ORAL DISCUSSION

R. S. MacPherran: The approach to this problem may be made in two ways. The more usual method would be to determine the separate effects of silicon, carbon, nickel, chromium, etc., by making synthetic irons, then translating these effects into the iron which would be found best to use. The other method—the one we adopted in this paper—was to take mixtures actually in use in our own foundry and determine the effects of various heatings on these mixtures.

All the specimens made in these tests were taken from our regular foundry run with or without the ladle addition of nickel and chromium. We thought this to be a simpler method of approach and, in the long run, more satisfactory to us.

In the main, our idea was to determine the relative values at high temperature and under long service of mixtures actually in use in our own foundries. We might mention here that the mixture referred to as "A" contained about 22 per cent steel, and the mixture referred to as "HT" contained over 90 per cent steel.

In paragraph 56 of the paper there is a statement that it should be remembered that there is nothing in these tests to indicate that after 500 hours at that temperature (1,120 degs. Fahr.) the maximum effect had been reached. Since writing this paper, we have continued the heating of Series *B* at 950 degs. Fahr, for an additional 1,500 hours, or a total of 2,000 hours. The results are shown in Table 13.

We find a continual although somewhat decreasing loss in physical properties from period to period. In "HT"-31, for example, the first period of 500 hours shows a drop in combined carbon of 86 per cent with only 5½ per cent additional in the third and fourth periods. It loses in tensile strength 24½ per cent in the first period and 6.1 per cent in the third and fourth periods.

The specimen least affected is the one marked "ACr"-30, containing chromium. This loses 16 per cent of the combined carbon in the first period and 10 per cent in the third and fourth periods. It loses 2.6 per cent of hardness in the first period and 1.7 per cent in the third and fourth periods. It loses 5 per cent of its tensile strength in the first period and 3½ per cent in the third and fourth periods.

Similar losses occur in the other specimens, and it would seem that the curve, although flattening out, still tends to go lower in value.

It might be well to point out that when, in paragraph 52, we refer

Table 13

(Series B)

EFFECTS OF HEATING AT 950 DEGS. FAHR. FOR PERIODS OF 500 HOURS EACH

PER CENT LOSS IN COMBINED CARBON

	Loss in CC, %			
	"HT"-31	"HT Cr"-32	"A"-29	"A Cr"-30
1st period	86.4	27.9	86.4	16.2
2nd period	8.1	0.0	1.2	8.0
3rd and 4th period.....	5.5	22.7	12.4	10.3
Tot. loss in CC, %....	100.0	50.6	100.0	34.5

PER CENT LOSS IN BRINELL HARDNESS

	Loss in brinnell, %			
	"HT"-31	"HT Cr"-32	"A"-29	"A Cr"-30
1st period	23.5	3.7	22.8	2.6
2nd period	5.5	0.0	7.1	1.4
3rd and 4th period.....	5.2	5.7	2.7	1.7
Tot. loss in brinell, %	34.2	9.4	32.6	5.7

PER CENT LOSS IN TENSILE STRENGTH

	Loss in tensile strength, %			
	"HT"-31	"HT Cr"-32	"A"-29	"A Cr"-30
1st period	24.5	3.0	23.9	5.0
2nd period	4.2	0.0	4.2	0.0
3rd and 4th period.....	6.1	4.8	4.2	3.5
Tot. loss in tensile strength, %	34.8	7.8	32.3	8.5

to nickel as accelerating the decomposition of pearlite, we have in mind its direct effect only. It might be fair, however, to consider that when using nickel it is possible to lower the percentage of silicon, which would tend to lessen this effect of nickel.

As to the paper itself, we have put in several photomicrographs showing various gas liners and oil liners, in some instances after four years and in others after 17 years' operation, showing the effect of long-time service at moderate temperatures. The temperature of operation is a bit uncertain, because various engineers gave us different temperatures. One engineer said his liner would run about 700 degs. Fahr., and another said about 1100 degs. Fahr. There was so much diversity that we did not try to insert the temperature of the operation in the paper.

However, in Fig. 16, *E*, the cementite has been pretty well spheroidized. In Fig 16, *A*—the marine diesel liner of European manufacture—the entire character of the cast iron has been changed. All the cementite has been spheroidized and the entire structure has been altered until it is almost like steel.

Dr. R. Moldenke:* The casting foundry seems to demand one thing, and that is to try to get the stresses out of the castings without changing the character of the composition. Mr. MacPherran, do you know, in your work, at what point you can say the stresses have left the casting? Have you found the temperature at which the stresses are out of a casting and yet have left it of the same composition? If, in taking the stresses out, one changes the character of the casting, one may not have what he started out to make.

A man once came to me to find out why a printing-press cylinder was machined. About six months after this cylinder had been shipped out and installed, a report came in that a little flattening was noticeable, an amount of a few thousandths of an inch but just enough to condemn the cylinder. The point was this: In heating that casting up to where it would not soften, nothing happened to it which was likely to prove dangerous afterward, yet the stresses were out of it.

R. S. MacPherran: We have made no definite experiment at our plant on the question of the complete relief of stress. However, we did make some experiments some years ago as to the softening effect. We have found that we can go up for three hours to about 950 degs. Fahr. without any special effect on the hardness or the strength.

Dr. R. Moldenke: In annealing the castings, were you able to keep the temperature below 950 degs. Fahr.? I ask this because, in some irons, the casting stresses can be removed at temperatures not over 800 degs. Fahr. Going up, say, to 1000 degs. Fahr. would already affect the stability of the combined carbon present, and therefore would change the character of the castings considerably.

R. S. MacPherran: We have made no experiments to determine the relief of stress. We simply go as high as we can go without any soften-

*Watchung, N. J.

ing effect appearing. We want to be sure to relieve all the stress we can, so we go up to about 950 degrees without any apparent change in the strength or hardness.

To sum up this paper briefly, we find that a high-silicon, low-carbon iron, with or without nickel, softens and weakens on heating.

We had hoped to use this iron for operations where high temperatures are encountered, for instance in mining work and kiln work and places where high temperatures are necessary. We wanted to use this high-test iron at perhaps 1000 degs. Fahr., and we hoped that it would work out and hold up in strength and hardness; but it does not. The only way we find to maintain strength and hardness at high temperatures is to put in chromium.

We also found that the softening effect is continuous. It was reported by some investigators that, after 100 or 200 hours, this softening effect ceased. We do not find that to be the case.

We kept up the heating for 2000 hours, that is, a three months' run, at 950 degs. Fahr., and we found that the softening effect and the weakening effect never ceased—the iron simply kept on getting softer and weaker. Inasmuch as we are making machines to last, not for two weeks but for twenty years, we cannot afford to put in iron that is going to soften and weaken in a few months.

WRITTEN DISCUSSION

JOHN SHAW:* The investigation by Messrs. MacPherran and Krueger carries us a step further than the excellent work done by Donaldson, inasmuch as the heat treatment is not only for a longer period, but as there are also only two breaks in series *A* and none in series *B*. The temperature ranges are also more varied, and are carried higher.

One thing is made clear, namely, that 800 degs. Fahr. is about the maximum temperature for cast iron to maintain its strength and prevent loss of combined carbon *under the conditions obtaining in the present investigations.*

This figure is approximately the same as contained in some specifications in this country, *i.e.*, 400 degs. Cent. or 752 degs. Fahr. However, these conditions, where the specimen is entirely enveloped in the heating medium, are seldom found in actual practice.

With one of the worst examples, a superheated pipe line, there is a temperature gradient from the outside to the inside surface of the pipe. This tends quickly to equalize matters, and even surface cracks are seldom found if the metal is sound and of suitable composition.

The authors quote a passage from the paper of Campbell and Glassford. Little proof is given to substantiate the statement and the fact

*Southsea, England.

that, in the previous paragraph, the same authority states: "After microscopic examinations of inlet fittings (saturated steam) and outlet fittings (superheated steam), he found no difference in the structure of the iron and gave it as his opinion that none need be expected below 700 degs. Fahr."

Primrose, in the same paper, states: "Certain cast-iron fittings that have been in use in the superheater of a boiler in gases at 1000 to 1200 degs. Fahr., and containing steam at 175 lbs. pressure and superheated 150 degs. Fahr., were in use eight years and then showed no sign of defect."

It might have been as well, while quoting Campbell and Glassford, if the conclusions had been given from the three papers[5] from which these authors obtained much of their information. Hollis states: "The reason for the substitution of steel fittings in the pipe line ought not to be lost sight of, if cast iron is to be judged fairly. It was made because it was cheaper to replace the cast iron tees in steel rather than to put in expansion or slip joints."

Mann, in the same series of papers, stated: "Out of 25 steel gate valves of 6, 8 and 10 in. diameter, not more than four were tight after one year's service. . . . . It would appear.....that some material better than the ordinary steel casting was desirable for high-temperature work. Such a material is gun iron." An approximate analysis is given as—C 3.0 per cent, Si 1.4, Mn 0.45, S 0.06, P 0.20.

In the third paper of this series, Miller subjected gun iron, ordinary cast iron, semi-steel and steel to the effect of superheated and saturated steam, alternately, by suspending samples of each in the interior of a pipe. The pressure was 93 lbs. and average temperature 660 degs. Fahr., with a maximum of 720 degs. Fahr. After being exposed to superheated steam for 260 hours, and at night to saturated steam for 460 hours, the loss in strength was as follows:

First type....ordinary cast iron lost 9.5 per cent in strength.
Second type..ordinary cast iron lost 2.4 per cent in strength.
Gun iron.....lost 2.1 per cent in strength.
Semi-steel.....lost 0.4 per cent in strength.*
Steel.....lost 1.9 per cent in strength.†

*Direct steel addition molten.
†75,000 to 80,000 lbs. tensile.

These results are probably due to corrosion and pitting rather than to altered structure. From the information now available, it may be taken for granted that any failure at normal pressure and temperatures below 800 degs. Fahr. is due to one or more of three causes:

(1) Wrong design (whether in the casting or layout).
(2) Casting faults, out of section, segregation or dirty areas.
(3) Unsuitable analysis.

[5]*Foundry*, January, 1910, p. 196.

Table 14

COMPARISON OF ANALYSES AND PROPERTIES OF VARIOUS GRAY CAST IRONS—BY DONALDSON, AND BY MacPHERRAN AND KRUEGER

	Before heating											After heating: 842° F. for 200 hrs.			After heating: 1022° F. for 200 hrs.		
Iron.	TC	CC	Si	Mn	S	P	Ni	Cr	Tens., lbs. per sq. in.	Brinell.	CC	Tens., lbs. per sq. in.	Brinell.	CC	Tens., lbs. per sq. in.	Brinell.
(*)	3.51	.65	1.28	.89	.10	.34	...	...	29,600	207	.44	.....	163	.23	26,200	131
(*)	3.27	.78	1.03	.88	.08	.20	...	...	35,400	229	.65	32,000	207	.56	29,800	193
(*)	3.08	.76	1.1	.91	.12	.22	...	...	38,500	229	.52	36,900	179	.30	35,100	143
Ni Cr* ..	3.30	.76	1.89	.71	.06	.21	.24	.49	35,600	....	.57	33,400	...	.37	30,900	...
Cr*	3.17	.93	1.4	.97	.04	.69	...	.39	41,200	248	.69	38,700	207	.49	36,700	170
Perlit* ..	3.35	.91	.65	.85	.12	.17	...	...	41,000	217	.80	39,200	201	.72	39,200	192

	Before heating										After heating: A, 850° F.; B, 870° F.; for 500 hrs.			After heating: A, 1000° F.; B, 1020° F.; for 500 hrs.		
No. 1 (A)† ..	3.66	.76	1.24	.55	.07	.42	.02	.02	32,350	196	.71	32,350	197	.12	23,700	133
No. 29 (B)† ..	3.63	.73	1.15	.54	.09	.17	.03	.03	32,300	184	.61	32,700	187	.09	29,300	116
No. 2-Ni (A)† ..	3.61	.73	1.12	.90	.08	.19	.90	.03	35,500	199	.70	35,100	196	.07	23,550	125
No. 11-Ni (A)† ..	2.77	.76	1.84	.69	.09	.08	2.46	.02	69,100	272	.75	64,000	271	.08	48,000	181
No. 30-Cr (B)† ..	3.46	.87	1.36	.68	.085	.39	.015	.54	41,900	227	.83	41,800	232	.68	38,900	207
Liner, new† ..	3.12	.79	.92	.82	.113	.34	...	...	45,500	226	...	.....	...	...	.....	...
4½ years service†	3.15	.73	.96	.86	.115	.34	...	...	34,300	197	...	.....	...	...	.....	...
17 years service†	3.38	.80	.75	.58	.108	.45	...	..	32,800	177	...	.....	...	...	.....	...

*Iron of Donaldson investigation.
†Iron of MacPherran and Krueger investigation.

No doubt it was the object of the authors to enforce this last point that caused them to use several of the analyses in this investigation. A comparison between these and what is evidently their standard analyses as contained in the liner makes this evident.

It has been recognized for some time that low silicon and low carbon are required in high temperature work if strength and loss of combined carbon are to be avoided, and the authors' conclusions confirm this. Donaldson states that there is a critical silicon content, about 1.17 per cent, above which growth is more rapid.

Table 14 presents a few analyses from Donaldson's work, and others from the present investigation.

Donaldson only tried two temperatures—200 hours at 842 degs. Fahr. and 200 hours at 1,022 degs. Fahr. In order that comparisons can be made, the results of the present investigation have been confined to the results obtained at 850 and 1,000 degs. Fahr. in the *A* series and 870 and 1,020 degs. Fahr. in the *B* series. The comparison should show the effect of the longer heating period of 500 hours against the 200 hours.

A comparison of the two sets of analyses does show the effect of the extra time at 1,000 degs. Fahr. This would have been more pronounced if Donaldson's experimental irons had not been cooled each day.

The effect of chrome is not so definite in Donaldson's iron as in the present authors' No. 30. An increase to 0.54 per cent might have helped, but the reason probably is due to another cause.

While it is never wise to draw conclusions from a few examples, it would appear that the effect of chrome is about equal to the effect of low silicon in stabilizing the carbide and maintaining strength at 1,000 degs. Fahr. by comparing No. 30 with the Perlit iron. It may also be noted that all the irons in both groups are pearlitic as cast, but that the tensile strength varies from 14 tons to 30 tons. Much of this difference could be put down to the form and quantity of the graphite present.

On comparing the two groups of analyses, it would seem that the T C + Si + Ni is much higher for the same combined carbon than in Donaldson's group. Is this due to a higher percentage of steel in the charge?

In view of the analyses, the tensile strength of bar No. 11 is remarkable. If we consider that three of Ni equals one of Si, we get a TC + Si of 5.43 per cent and a tensile strength of 30.8 long tons per square inch. Equally remarkable is the fact that, after exposure at 1,000 degs. Fahr. for 500 hours and the combined carbon reduced to 0.06 per cent, a bar should yet break at 48,000 lbs. per square inch.

A glance at Fig. 12 shows fairly large expanded graphite, and it would be interesting if the authors would let us have their views on this matter. At all events, it shows the futility of expecting the brinell number to give any idea of the combined carbon content unless it is on the same type of metal made in the same manner. We have here a brinell of 181 with a combined carbon of 0.06 per cent, while in No. 2,

still with Ni present, the brinell is only 199 with a combined carbon of 0.73 per cent.

As a final point, No. 5, a bar of 2 in. diameter, and No. 9, a bar of 3¼ in. diameter, are cast of the same mixture. At room temperatures, there is the drop in the tensile strength in the large bar, per square inch, one would expect from the more open center. However, when both are held at 1,000 degs. Fahr. for 500 hours, the 3¼ in. bar is then the strongest per square inch. That is, there is a drop of 28 per cent on the small bar and only 11 per cent on the large bar, although both are turned the same size for testing purposes.

How do the authors account for this? Is it due to lack of gas penetration, and would time regulate this?

WRITTEN DISCUSSION

DR. J. W. DONALDSON* wrote that he had read the manuscript by Messrs. MacPherran and Krueger with considerable interest. He was pleased to see that the authors using similar methods of testing to his own, and applying them to irons used in their own foundry, had obtained results which agreed with those he had obtained in his various investigations.

There were one or two points he desired to refer to. In paragraph 15 the authors stated that they found no effect when heating up to and including 800 degrees Fahrenheit for a period of 500 hours. Dr. Donaldson was rather surprised at this because, in his experiments, he had found slight changes at 200 degrees Centigrade (392 degrees Fahrenheit) and marked changes at 250 degrees Centigrade (482 degrees Fahrenheit), and he stated that these temperatures are important when one is dealing with iron exposed to the influence of saturated and superheated steam.

The authors referred to the continued loss in tensile strength and brinell hardness from week to week and even after the entire decomposition of the carbide had been accomplished. Dr. Donaldson said he had noticed a similar loss in strength and hardness after decomposition of the carbide had become stable, and he considered this further loss to be due to oxidation of the iron in the vicinity of the graphite flakes.

He was in agreement with the authors that the graphite from the decomposed pearlite tended to migrate toward the existing graphite plates, and that these plates became swollen. He had also found, especially with high-carbon and high-silicon irons, that decomposition was accompanied by oxidation of iron, and he said he would be interested to learn if the authors had observed this to take place during their experiments.

The data on liner castings was very interesting. An instance of

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the effect of exposing cast iron to high temperatures for a prolonged period which he had dealt with was in connection with a marine diesel piston. This piston—which had an original composition of total carbon 3.09 per cent; combined carbon 0.72; graphitic carbon 2.37; silicon 1.65; sulphur 0.053; phosphorus 0.713 and manganese 1.05—was in operation for 51,000 miles—4,850 hours running—when it cracked on the top and at the ring grooves. Analyses taken at these parts were as follows: Total carbon 3.03 per cent; combined carbon, a trace; graphitic carbon 3.03; and total carbon 3.04 per cent, combined carbon 0.33, graphitic carbon 2.71. A micro-section taken from the top of the piston showed complete decomposition of the pearlite and a very marked coarsening of the graphite plates.

REPLY BY AUTHOR

R. S. MacPherran: Referring to Mr. Donaldson's comments on our results which show no action below 800 degs. Fahr., I am unable to account for this difference. We made tests at 600, 700, 750 and 800 degs. Fahr., and in no case found any change. His results show a distinct action at much lower temperatures.

The only difference between our tests is that our operation was a continuous heat for the 500 hours. Mr. Donaldson heated his specimen for eight hours and then cooled overnight. It is a matter of common knowledge that alternate heatings and coolings have more effect than one continuous heat.

Regarding the comments of Mr. Shaw, to avoid padding our paper with too many quotations we endeavored to reduce these to a minimum. In the case of the one from Campbell and Glassford, evidently we overdid it. The conclusions there given were uncertain and to some extent contradictory.

Mr. Shaw is correct in his idea that the iron used in our liners is our standard mixture for high-temperature service. We had hoped that the high-test iron would be satisfactory, but results were to the contrary.

In regard to bar No. 11, Series *A*, this structure was unusually fine, almost like steel, which may account for its good physical properties. It is fair to state, however, that bars Nos. 5 and 9 show no greater loss of strength at 1,000 degs. Fahr. than this bar No. 11.

In our experience with high-test iron, the high silicon does not seem to affect the strength as much as low carbon. This latter is almost essential to a high breaking load.

We are inclined to agree with Mr. Shaw about the difficulty of expecting a brinell test to show the combined carbon.

We noticed the difference in the breaking loads of bars Nos. 5 and 9,

Series *A*, but have no very good explanation to offer. The smaller bar naturally cooled more quickly and was stronger in the "as cast" condition. The annealing at 900 and 950 degs. Fahr. overcame this difference and equalized the structure. We could see no reason for any final difference in strength.

Some Phases of Heat Treatment of Cylinder and Alloy Irons

By F. J. Walls* and A. Hartwell, Jr.,** Pontiac, Mich.

Abstract

The authors deal with the relief of stresses and the physical changes of cylinder irons with various heat treatments, and with some effects of heat treatment on chromium-molybdenum and chromium-nickel-manganese cast irons. For investigation of relief of stresses, a special test bar was designed. Tests were run showing relief of stresses after holding at temperatures of 750 to 1150 degs. Fahr. Heat treating as affecting hardness was thoroughly investigated, tests being run on air—water—and oil-quenched specimens. In conclusion the authors state that, to obtain maximum relief of stresses and a minimum of growth and change in hardness, heat at 950 degs. Fahr. and follow by slow cooling; to obtain dead-soft iron, heat just below the critical point and air cool; for the irons investigated, to obtain hard cast iron, heat to 1500 degs. Fahr. and quench in water; for irons with higher silicon content, heat much higher than 1500 degs. Fahr. to dissolve enough graphite to give maximum hardness on cooling.

1. Cast iron ordinarily is heat treated to bring about either or both of two distinct changes: First, dimensional or mechanical changes of the specimen, and second, physical changes in the properties of the metal itself.

2. Under mechanical changes, the casting may be heated to change its dimensions or insure a fixed dimension after machining by eliminating the growth, at least partially. More important is the thermal process of relieving stresses, for there are many cases where distortion caused by machining or casting stresses may ruin a casting.

3. The physical properties may be changed by annealing to produce softer and more machinable castings, by heating and

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Table 1

RELIEVING STRESSES IN IRON CASTINGS

Temp. of heating degs. Fahr.	Hours at heating	Av. growth, inches.	Av. expansion, inches.	Original brinell.	Final brinell.
As cast	.	.....	0.0315	179	...
As cast	.	.....	0.0290	187	...
750	3	0.0002	0.0238	179	179
750	1	0.0006	0.0228	179	179
850	3	0.0012	0.0136	179	179
850	1	0.0012	0.0144	179	179
950	3	0.0010	0.0061	183	183
950	1	0.0017	0.0086	179	179
1050	3	0.005	0.0023	187	183
1050	1	0.0021	0.0024	179	179
1150	3	0.0130	0.0008	183	166
1150	1	0.0043	0.0004	179	172

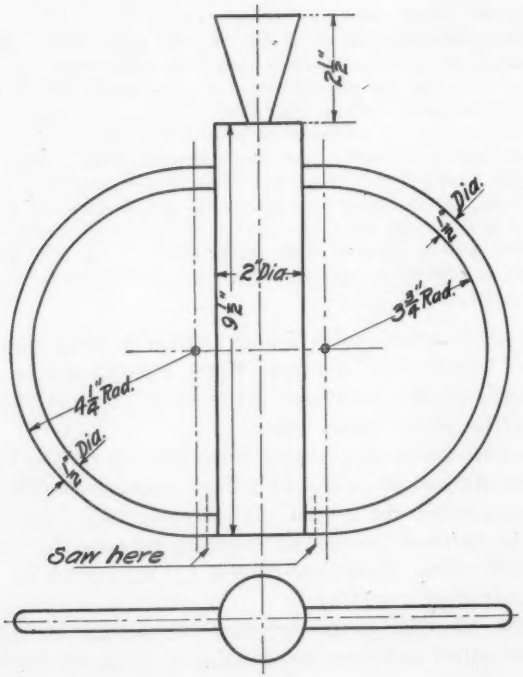

FIG. 1—DESIGN OF TEST BAR USED TO SHOW RELIEF OF STRESSES.

quenching to obtain a hard material, or by carburizing to produce a hard surface. The amount of change effected by these processes will depend on the character of the iron used.

4. This paper will consider the relief of stresses in cylinder iron, the physical changes of cylinder iron with various heat treatments and some of the physical changes of chrome-molybdenum and chrome-nickel-manganese irons.

Relief of Casting Stresses

5. The tolerances in modern machine work are being reduced to a point where it becomes necessary to eliminate distortion due to casting stresses. The old method of weathering or aging castings outdoors for months, required a tremendous inventory and storage space. The press of competition and rapid changes in models has made it necessary to find some rapid means of relieving, or at least reducing the stresses.

6. To determine whether or not stresses are relieved, it is necessary to find some means of quantitatively measuring them or their effect. A number of bars were tried, such as a flat bar machined on one side, and a flat bar bent and held for some time to produce a permanent set. None of these gave consistant results.

7. The test bar finally used is shown in Fig. 1. Two runs were made with these bars. Three bars were measured as cast, cut, and then remeasured. Three bars were then heated to each of the following Fahrenheit temperatures: 750, 850, 950, 1050 and 1150 degrees. These were held at temperature for three hours and cooled to 400 degs. Fahr. in the furnace.

8. The second run was a duplicate of the first, except that the bars were held for only one hour at temperature and then cooled to 200 degs. Fahr. in the furnace.

9. All bars were measured before heating, after heating, and after cutting. The brinell hardness of each bar was taken before and after heating. Photomicrographs were made on one bar of each series.

10. The average results are shown in Table 1. A graph showing the relation between temperature and growth and expansion is given in Fig. 2.

11. The permanent growth, as shown by the measurements before and after heat treatment, shows a steady increase up to

1000 degrees and then goes up rapidly. The expansion shows a drop at 750 degrees and a rather rapid decrease from there to 1000 degrees, where the rate of change with temperature is decidedly less.

12. The brinell hardness showed no change up to 1050 degrees, and at that point a slight softening took place after three hours heating; no softening was noticeable after one hour at temperature. At 1150 degrees the decrease in hardness amounted to 16 points brinell after three hours, and 7 points when held for 1 hour. Examination of specimens at 500-diameters magnification showed no change in the microstructure.

13. With these results as a guide, we have established the following treatment for relieving stresses in castings without changing the hardness. The castings are put on racks brought up to 950-975 degs. Fahr., held there for two hours and then

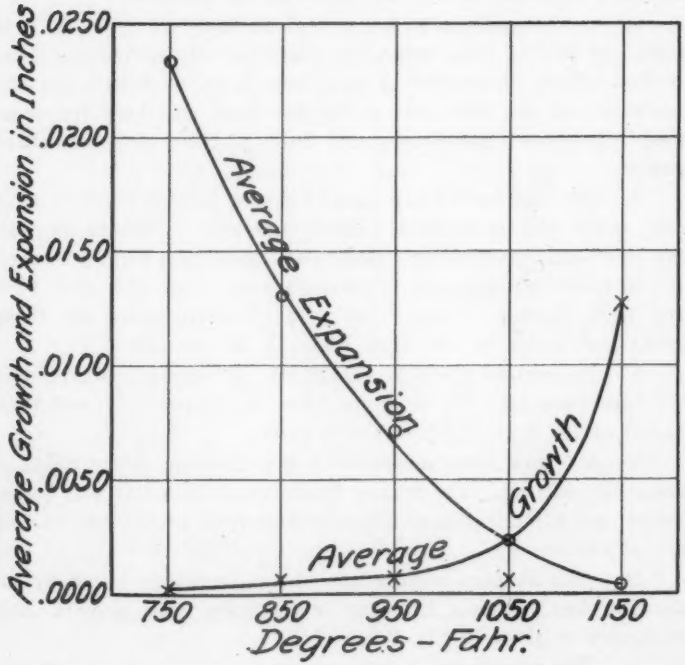

FIG. 2—GROWTH AND EXPANSION AS AFFECTED BY TEMPERATURE OF HEATING.

cooled for three hours. The furnace is of the oil-fired muffle type. There is a sheet metal cooling zone at the end of the furnace in which the castings stay for one-half of their cooling time.

14. The cooling in the metal chamber is more rapid than in the brick oven, but at the same time no drafts or cold air currents strike the sleeves directly. Slow, even cooling is very important. Rapid, uneven cooling will set up new stresses and the resultant casting will distort, even though the original stresses were relieved by the heating.

15. If the strength and hardness of the castings are not important, the temperature of heating may be increased, and with the resultant structural changes will come a more complete relief of stresses.

Physical Property Changes of Cylinder Iron

16. The first series of tests were made on gray iron in the following range of chemical composition:

	Per Cent
Silicon	2.27-2.33
Sulphur	0.081-0.087
Phosphorus	0.202-0.210
Manganese	0.70-0.75
Total carbon	3.30-3.35
Combined carbon	0.52-0.55

17. A thermal curve was made to determine the critical point at an ordinary rate of heating. There was no distinct arrest, but there is a break in the curve at 1460-1480 degs. Fahr. A thermal curve was also run on castings cooling after they were shaken from the mold. The two critical points found were at 1400 and 1340 degs. Fahr. The thermal curves are shown in Fig. 3.

18. A series of tests were made to determine the softening point. Seven pieces, 1-inch cubes, were placed in a muffle furnace and heated slowly to insure uniform distribution of heat. At 1150 degs. Fahr. one piece was withdrawn and air cooled. From then on a piece was removed after each 25 degree rise up to 1250 degs. Fahr. At 1250 degs. Fahr. one piece was removed after 11 minutes and another after 20 minutes. Brinell hardness was taken before and after heating on each piece. The results are shown in Table 2.

19. A further check of the effect on hardness was made, this time using temperatures both above and below the critical point. Three quenching mediums were used—air, oil and water. The results are shown in Table 3, and a hardness-temperature curve in Fig. 4.

20. The hardness of the air cooled specimens decreased to a point some 45 degrees above the critical range. Above this temperature the hardness increased again. In the oil-cooled

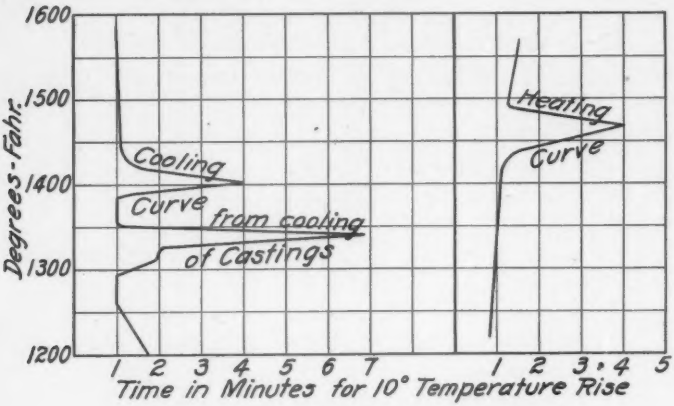

FIG. 3—CRITICAL POINT CURVE OF CYLINDER IRON.

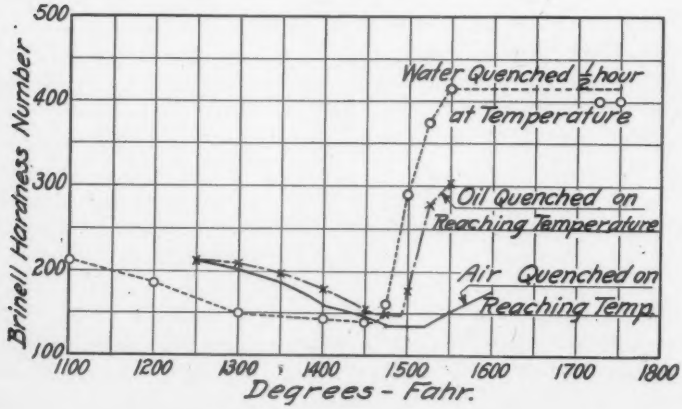

FIG. 4—HARDNESS-TEMPERATURE CURVE FOR CYLINDER IRON.

pieces the minimum hardness was obtained at 1475 degs. Fahr., and for the water quenched, at 1450 degs. Fahr.

21. This difference undoubtedly is due to the slower rates of cooling of the air- and oil-quenched specimens, allowing softening to take place just below or at the critical range. The explanation may be seen more readily when we discuss the microstructure of the specimens.

22. The great changes in hardness were expected to be accompanied by proportionately great changes in strength. We cast test bars for a tensile test twice a day. The size and method of gating is given in Fig. 5.

23. One bar from each mold was pulled as cast; the other was heat treated and then tested. The hardness was taken on each end of the bars and a section polished. Photomicrographs were taken of the bars with distinctive properties. Duplicate tests were run for each treatment.

24. The first lot were held at temperature for 30 minutes, quenched in water and drawn at 400 degs. Fahr. for one hour. The results are shown in Table 4. A further series of tests were made to determine the effect, if any, of the other treatments—particularly with long-time soaking. Table 5 shows the results obtained.

25. The tensile tests on these two series show that it is possible to greatly increase the strength as well as the hardness of cast iron by heat treatment. They show that a quench from the high side of the critical range, or just above—that is, from 1480 to 1525 degs. Fahr.—with the proper draw, seems to give the best properties. Some of the other bars, notably those air cooled from 1800 degrees, give a somewhat higher strength with a lower brinell hardness.

Table 2

Data on Softening Point in Cast Iron

Temp., degs. Fahr.	Hardness before heating	Hardness after heating	Minutes, at temp.
1150	207	207	..
1175	207	207	..
1200	207	207	..
1225	207	207	..
1250	207	207	..
1250	207	170	11
1250	207	143	20

Table 3

EFFECT OF QUENCHING MEDIUMS

Temp. of heating, degs. Fahr.	Quenching medium	Original hardness	Final hardness	Time at temp., minutes
1250	Air	217	212	..
1300	Air	217	202	..
1350	Air	212	187	..
1400	Air	223	159	..
1450	Air	212	149	..
1475	Air	212	134	..
1500	Air	217	137	..
1525	Air	212	137	..
1550	Air	217	152	..
1600	Air	212	174	..
1250	Oil	212	212	..
1300	Oil	217	207	..
1350	Oil	212	197	..
1400	Oil	212	179	..
1450	Oil	217	156	..
1475	Oil	217	149	..
1500	Oil	217	179	..
1525	Oil	212	277	..
1550	Oil	217	302	..
1100	Water	212	207	10
1100	Water	212	217	20
1100	Water	212	212	30
1200	Water	212	202	10
1200	Water	217	197	20
1200	Water	207	184	30
1300	Water	212	152	10
1300	Water	212	149	20
1300	Water	217	140	30
1400	Water	212	149	10
1400	Water	212	140	20
1400	Water	212	137	30
1475	Water	217	163	5
1500	Water	207	277	10
1500	Water	207	269	20
1500	Water	207	293	30
1525	Water	212	375	5
1550	Water	201	415	10
1550	Water	207	415	20
1550	Water	212	415	30
1750	Water	212	400	20 hrs.
1725	Water	217	400	48 hrs.

NOTE: The last two bars were reheated to 1150 degrees for 20 minutes; the brinell hardness was 242. A chill bar which brinelled 514 was heated to 1460 degrees, furnace cooled to 1300 degrees in 45 minutes, and then air cooled; the hardness was then 174.

26. The microstructure is shown in Figs. 11*A* to 13*B*, inclusive. The graphite in the iron as cast shows no difference from that in Fig. 13*A*. The matrix of the iron is almost entirely a sorbitic pearlite.

27. Figs. 11*A* and 11*B* show the effect upon the matrix of heating to 1400 and 1600 degrees, followed by air cooling. The pearlite has been almost entirely destroyed at 1400 degrees and the remainder is segregated near the graphite flakes. At 1600 degrees, however, there is much more combined carbon distributed more evenly. There is less, however, than in the original sample.

28. Figs. 11*C*, 11*D*, 11*E* and 12*A* show bars heated in the critical range and above it, the first two oil quenched and the second water quenched. These both show the small amount of pearlite on heating below the critical.

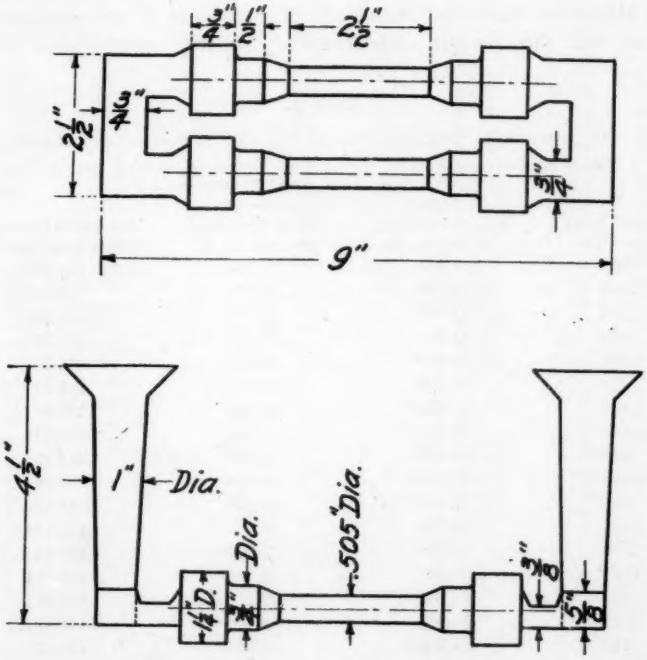

FIG. 5—TEST BARS DESIGNED FOR TESTING TENSILE STRENGTH OF CAST IRON.

29. Fig. 12*A* shows martensite formed but with about the usual amount of graphite. This bar was drawn at 1150 degrees to show the amount of pearlite which would be formed from the amount of carbon dissolved above the critical point upon long soaking. It is shown in Fig. 12*B*. Another bar, heated for 24 hours longer, showed no difference in either matrix or graphite.

30. Figs. 12*C*, 12*D*, 12*E*, 12*F*, 13*A* and 13*B* show the structure of tensile bars before and after etching. The matrix of the three bars as shown in the etched samples accounts for the difference in tensile strength. The hard bar in Fig. 12*D* is very brittle, and the graphite flakes produce a notch effect. As the matrix has little ductility, a local over-stress soon produces rupture across the bar. Slight irregularities in the bearing surface of the bar may produce bending stresses, which more quickly produce rupture than in the softer iron.

31. Fig. 12*F* shows the structure at 500 magnification of the highest strength bar obtained. The graphite is not unusually small, but this matrix consisting of troostite and ferrite was

Table 4

EFFECT OF QUENCHING TEMPERATURE ON TENSILE STRENGTH AND HARDNESS

(Bars held at temperature for ½ hour. Water quenched, drawn at 400 degs. Fahr. for one hour.)

Quench temp., degs. Fahr.	Strength before heating, lbs. per sq. in.	Strength after heating, lbs. per sq. in.	Brinell hardness after treatments
1200	28,900	31,750	143-137
1300	33,700	30,500	137-140
1300	34,200	30,750	137-143
1400	34,200	31,750	137-137
1400	32,000	32,750	146-137
1450	30,100	49,500	197-341
1450	33,000	26,500	207-321
1480	32,200	28,500	388-341
1480	30,200	31,000	388-429
1500	31,600	42,500	286-444
1500	40,400	58,000	302,429
1525	36,000	40,000	444-444
1525	32,500	38,500	401-415
1550	33,300	36,000	415-415
1550	27,700	42,250	388-388
1720	28,000	19,000	444-444
1720	34,300	35,000	429-415
1800	36,000	4,500	477-477
1800	36,800	10,000	477-477

Table 5

EFFECTS OF VARIOUS HEAT TREATMENTS ON PHYSICAL PROPERTIES

Quench temp., degs. Fahr.	Quench medium.	Time at temp.	Drawing temp., degs. Fahr.	Time at draw.	Strength, *B* heat.	Strength, *A* heat.	Brinell, *A* heat.
1800	Furnace	1 hr.	....	.....	36,300	28,500	134-128
1800	Furnace	1 hr.	....	.....	29,600	28,000	134-128
1800	Air	1 hr.	....	.....	33,000	36,000	163-167
1800	Air	1 hr.	....	.....	26,100	30,750	170-170
1740	Water	1 hr.	....	.....	32,400	13,250	477-477
1740	Water	1 hr.	....	.....	29,600	7,750	495-477
1740	Water	3⅜ hrs.	....	.....	37,000	7,000	477-461
1740	Water	3⅜ hrs.	....	.....	34,200	10,750	461-477
1700	Water	2½ hrs.	....	.....	37,500	5,000	477-477
1700	Water	2½ hrs.	....	.....	32,200	18,625	477-461
1700	Water	2½ hrs.	1100	1 hr.	34,000	51,125	277-262
1700	Water	2½ hrs.	400	1 hr.	30,000	34,250	285-311
1700	Water	1 hr.	1300	40 min.	31,250	20,700	207
1700	Water	1 hr.	1300	40 min.	33,600	19,000	197
1700	Water	1 hr.	1100	30 min.	33,000	36,750	269
1700	Water	1 hr.	1100	30 min.	34,800	32,400	269
1700	Water	1 hr.	900	45 min.	33,000	25,750	331
1700	Water	1 hr.	900	45 min.	29,600	19,750	331
1560	Water	20 min.	....	.....	35,200	28,500	429
1560	Water	20 min.	....	1 hr.	36,400	21,000	429
1540	Water	24 hrs.	700	1 hr.	33,700	40,500	207-207
1540	Water	24 hrs.	900	1 hr.	33,000	39,375	197-179
1540	Water	24 hrs.	400	1 hr.	32,700	46,250	197-235
1600	Water	5 hrs.	....	.....	24,750	14,750	461-444
1600	Water	5 hrs.	....	.....	28,600	snapped	461-461
1500	Water	1 hr.	700	1 hr.	35,100	43,625	302-331
1500	Water	1 hr.	900	1 hr.	33,800	39,375	302-331
1500	Water	1 hr.	700	1 hr.	34,100	41,625	363-331
1500	Water	1 hr.	900	1 hr.	25,200(fl.)	34,750	293-269
1500	Water	1 hr.	1100	1 hr.	34,000	32,750	229-229
1500	Water	1 hr.	400	1 hr.	34,400	28,500	429-388
1500	Water	6½ hrs.	....	.....	24,600	14,250	444-429
1500	Water	6½ hrs.	....	.....	34,500	23,000	461-477
1500	Water	20 min.	....	.....	26,250	16,500	514
1500	Water	20 min.	....	.....	31,100	23,250	514
1460	Water	½ hr.	....	.....	34,000	38,000	170
1460	Water	½ hr.	....	.....	33,000	33,500	182
1400	Water	6 hrs.	....	.....	36,600	31,125	131-131
1400	Water	6 hrs.	....	.....	37,400	30,000	128-128
1300	Air	2¾ hrs.	....	.....	38,400	27,600	.....
1300	Air	2¾ hrs.	....	.....	35,800	28,500	.....
960	Air	35 min.	....	.....	34,700	35,200	207
960	Air	35 min.	....	.....	32,800	36,000	207

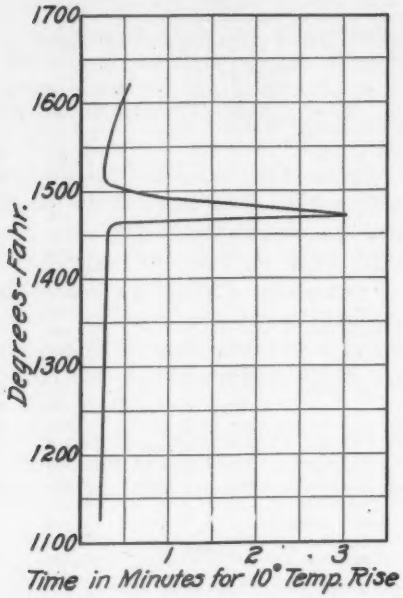

FIG. 6—CRITICAL-POINT CURVE OF A CHROME-MOLYBDENUM CAST IRON (IRON OF TABLE 6).

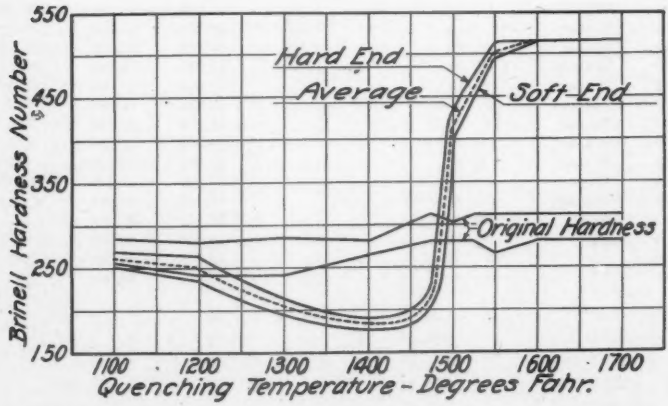

FIG. 7—BRINELL HARDNESS AS AFFECTED BY QUENCHING TEMPERATURES OF A CHROME-MOLYBDENUM CAST IRON (IRON OF TABLE 6). BARS 3 IN. LONG, ⅝-IN. DIAMETER. WATER QUENCHED. (SEE TABLE 7.)

Table 6

Chemical Analyses of Alloy Irons

	Analysis No. 3381	Analysis No. 3386
Silicon	2.16	2.23
Sulphur (evolution)	0.055	0.049
Phosphorus	0.187	0.196
Manganese	0.84	0.71
Total carbon	3.39	3.28
Chromium	0.22	0.16
Molybdenum	0.68	0.78

Table 7

Water Quenching Alloy Iron

Quench. temp., degs. Fahr.	Original hardness	Hardness after treatment
1100	255-286	248-268
1200	241-277	234-262
1300	241-286	197-214
1400	241-255	185-190
1450	248-277	180-202
1475	255-286	202-229
1500	255-277	388-429
1525	255-286	415-461
1550	241-286	495-514
1600	255-286	514-514
1700	255-286	Rock. C 57-59

Table 8

Air and Oil Quenching and Drawing of Alloy Iron

Temp., degs. Fahr.	Quench. medium	Hardness after treatment
1560	Air	179-187
1600	Air	197-212
1560	Oil	429-477
1500	Oil	269-352
1400	Oil	192-207
1490	Oil	255-363
(Drawing the last lot at 1220 degrees gave a brinell of 207 to 269.)		
1590	Water	514-514
1550	Water	Rock. C 48-55
(Drawn at 1120 degrees for 10 minutes, a Rockwell C of 24-32 and a brinell of 255 to 302 was obtained.)		

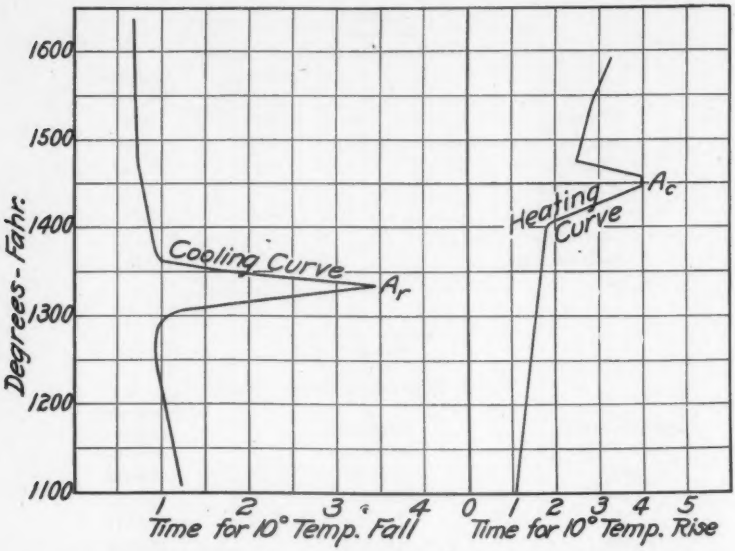

FIG. 8—HEATING AND COOLING CURVES OF A CHROME-NICKEL-MANGANESE CAST IRON (IRON OF TABLE 11). DATA OF QUENCHING AND COOLING GIVEN IN TABLE 12.

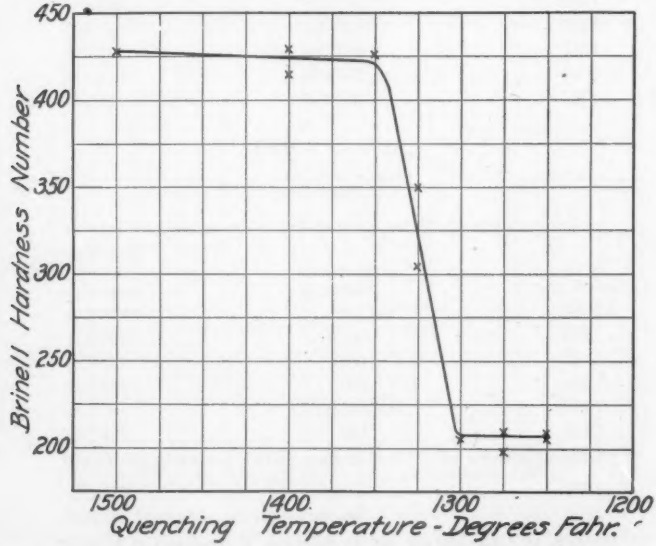

FIG. 9—EFFECT OF INDICATED COOLING TEMPERATURES ON A CHROME-NICKEL-MANGANESE CAST IRON QUENCHED AT INDICATED TEMPERATURES AFTER 1 HOUR AT 1500 DEGS. FAHR. (SEE TABLE 12.)

Table 9

EFFECT OF QUENCHING TEMPERATURE ON HARDNESS AND GRAPHITIZATION

Quench. temp., degs. Fahr.	Rockwell C hardness	Graphitic carbon
1775	55	2.45*
1675	53	2.48*
1575	51	2.51*
1425	47	2.66*
1375	20	2.63
1210	3	2.62

*These bars had to be drawn at 650 degrees so they could be drilled.

Table 10

EFFECT OF QUENCHING ON HARDNESS, TRANSVERSE LOAD, DEFLECTION AND TENSILE STRENGTH OF FOUR A. S. T. M. ARBITRATION BARS

Bar No.	Brinell			Ultimate transverse load, lbs. per sq. in.	Deflection at breaking point, inches	Tensile strength, lbs. per sq. in.
	Top	Middle	Bottom			
1	341	341	352	4400	.12	43,600
2	229	248	262	4600	.17	39,500
3	197	197	202	4200	.15	34,300
4	495	477	429	2200	.07	.....

Table 11

COMPOSITION OF CHROME-NICKEL-MANGANESE CAST IRON BARS TESTED

	Bar No. 1.	Bar No. 2.	Bar No. 3.	Bar No. 4.
Silicon	2.23	2.21	2.10	2.18
Sulphur (evolution)	0.053	0.051	0.057	0.050
Phosphorus	0.178	0.170	0.196	0.203
Manganese	1.10	1.09	1.05	1.10
Total carbon	3.24	3.34	3.06	3.19
Nickel	1.17	1.05	1.12	1.09
Chromium	.80	0.64	1.03	0.91
Brinell	269	255	269	262
Transverse, lbs. per sq. in.	3500	3200	Flaw	3000
Deflection, inches	0.13	0.13	...	0.12

found in all bars with greatly increased strength. We believe the strength is due to the troostite, with the free ferrite giving a little more than average ductility.

32. Fig. 13*B* shows a matrix which is almost completely ferrite. The strength was decreased by about 10 per cent, due to the change in the matrix.

33. Heating cast iron up to about 1050 degs. Fahr. for an hour produces no apparent physical change, stresses are relieved and a slight growth takes place. Above this temperature there is decomposition of the eutectoid cementite into graphite and ferrite. This change is accompanied by an increase in size, a slight decrease in strength and a great decrease in hardness. The amount of graphitization which takes place is dependent on the time and temperature.

34. H. A. Schwartz has stated that he has seen no evidence showing that graphitization does not proceed at any temperature, no matter how low. We have shown that 20 minutes at 1250 degrees produces a 64-point drop in brinell hardness, while quenching a bar as soon as temperature is reached, gives no change in hardness.

35. Dr. Anson Hayes has shown that iron carbide is unstable below the critical point. It is probable, therefore, that graphitization is proceeding at ordinary temperatures even though it is at an extremely slow rate. The speed of the reaction depends on the silicon content. The graphite apparently migrates to the old flakes, rather than forming new globules. The amount

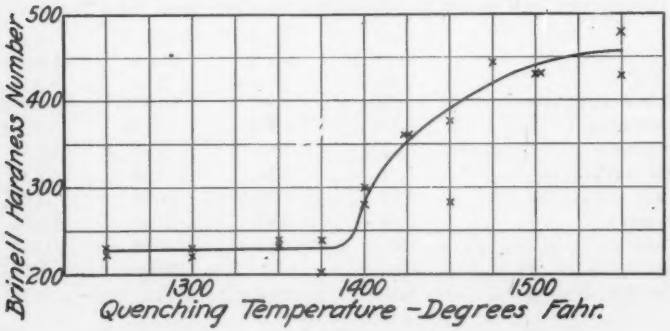

FIG. 10—BRINELL HARDNESS AS AFFECTED BY QUENCHING TEMPERATURE OF A CHROME-NICKEL-MANGANESE CAST IRON (IRON OF TABLE 11), QUENCHED ON A RISING TEMPERATURE. (SEE TABLE 12.)

will not be large even with complete graphitization, as 20 per cent extra graphite distributed around the outside of a flake is less noticeable than if used to form a new flake.

36. A piece heated to the critical point contains ferrite and graphite; it is in the dead-soft condition and weaker than the original iron. On heating above this point, the graphite tends to redissolve. The amount dissolved is dependent on the silicon content, the time and the temperature. Equilibrium diagrams by A. S. Norbury show a decreasing solubility of graphite with increasing silicon.

37. It is a question also of how soon equilibrium will be reached. By heating to 2000 degs. Fahr. it is theoretically possible to dissolve one per cent of graphite. The time required to reach this might be so long as to prevent its being practically reached. However, it might be possible—by quenching cast iron in a lead pot at 1150 degrees and then air cooling—to produce a small amount of graphite and a pearlitic matrix giving a higher tensile strength than is possible with the usual methods of heat treating.

38. Quenching from above the critical point brings structures in the matrix similar to quenched steel, with hardness similar to those obtained in steels.

Alloy Irons

39. The first series of tests were made on chrome-molybdenum cast iron. The chemical analyses of the two lots of castings tested were as given in Table 6.

40. A critical point run on heating shows the range to be 1470 to 1490 degs. Fahr. This is shown in Fig. 6.

41. The pieces used in this test were 3 in. long and $\frac{5}{8}$ in. in diameter. The hardness on the ends varied so it was necessary to test both ends. Samples of these were heated to the temperatures shown in Table 7 and quenched after 20 minutes. This is shown graphically in Fig. 7.

42. A series of miscellaneous tests of quenching and drawing temperatures gave the results shown in Table 8.

43. A third series of tests were made by heating to 1775 degs. Fahr., holding for two hours. They were cooled in the furnace and quenched at the indicated temperatures. Rockwell C hardness was taken and graphitic carbon run after treatment. The results are shown in Table 9.

Table 12

EFFECTS OF WATER QUENCHING CHROME-NICKEL-MANGANESE CAST IRONS.

Bar No.	Quench temp., degs. Fahr.	Brinell before treatment.	Brinell after treatment.
1	1240	235	235
2	1250	229	229
1	1300	248	229
2	1300	248	223
3	1350	241	241
4	1350	269	235
3	1375	285	241
4	1375	248	201
3	1400	255	286
4	1400	262	302
1	1400	241	302
2	1425	255	363
4	1425	248	363
1	1450	248	375
2	1450	248	285
2	1475	277	444
1	1500	241	429
2	1500	241	429
1	1550	255	429
2	1550	269	477
(Held at 1500 degrees for 1 hour. Cooled to indicated temperature and quenched.)			
1	1450	241	429
2	1450	241	429
1	1375	235	415
2	1375	248	429
3	1350	262	461
4	1350	241	444
1	1325	248	331
2	1325	269	375
3	1300	277	207
4	1300	255	207
3	1275	255	212
4	1275	269	197
3	1250	255	212
4	1250	277	217

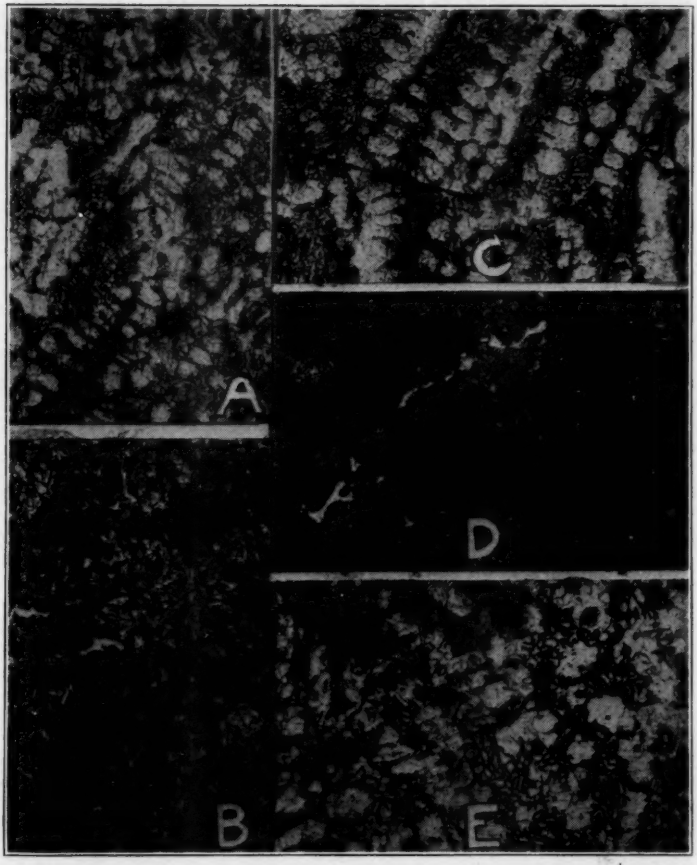

FIG. 11—QUENCHING SPECIMENS, ETCHED WITH 5 PER CENT HNO_3 IN ALCOHOL. 100X.

A, B: AIR QUENCHED. *A*—FROM 1400 DEGS. FAHR. *B*—FROM 1600 DEGS. FAHR.

C, D: OIL QUENCHED. *C*—FROM 1475 DEGS. FAHR. *D*—FROM 1525 DEGS. FAHR.

E: WATER QUENCHED FROM 1475 DEGS. FAHR.

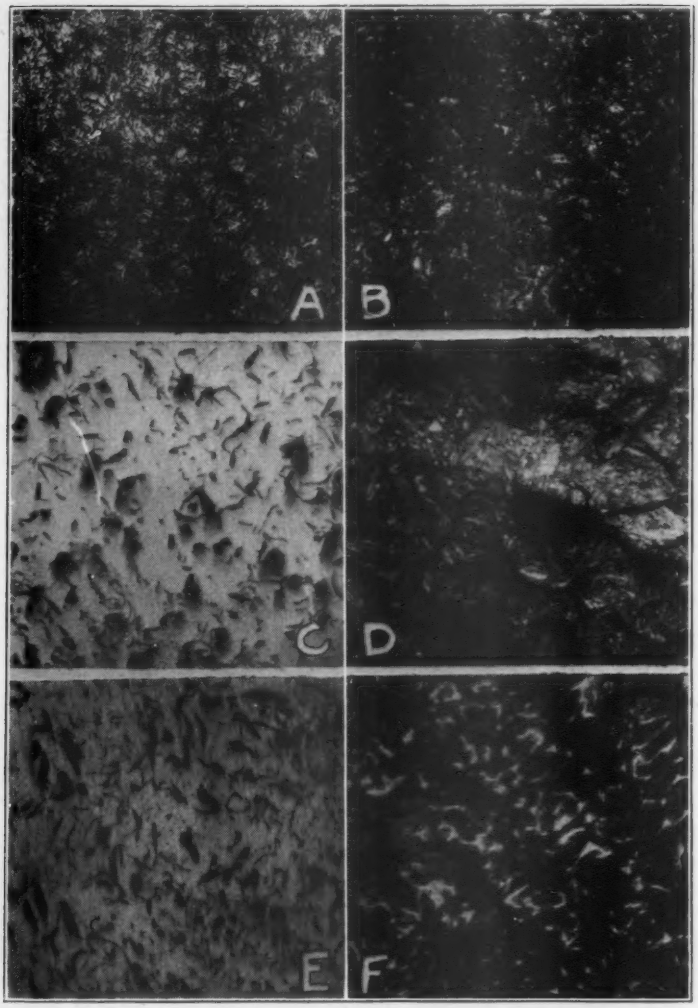

FIG. 12—*A:* QUENCHING SPECIMEN. WATER QUENCHED FROM 1725 DEGS. FAHR. AFTER SOAKING 20 HOURS. ETCHED WITH 5 PER CENT HNO_3 IN ALCOHOL, 100X.

B: SAME PIECE AS *A*, BUT DRAWN AT 1150 DEGS. FAHR.

C: TENSILE BAR. WATER QUENCHED FROM 1800 DEGS. FAHR., DRAWN AT 400 DEGS. FAHR. BRINELL 477, TENSILE STRENGTH 4500 LBS. PER SQ. IN. UNETCHED, 100X.

D: SAME AS *C*, BUT ETCHED WITH 5 PER CENT HNO_3, 500X.

E: TENSILE BAR. WATER QUENCHED FROM 1500 DEGS. FAHR., DRAWN AT 400 DEGS. FAHR. BRINELL 302-429, STRENGTH 58,000 LBS. PER SQ. IN. UNETCHED, 100X.

F: SAME AS *E*, BUT ETCHED WITH 5 PER CENT HNO_3, 500X.

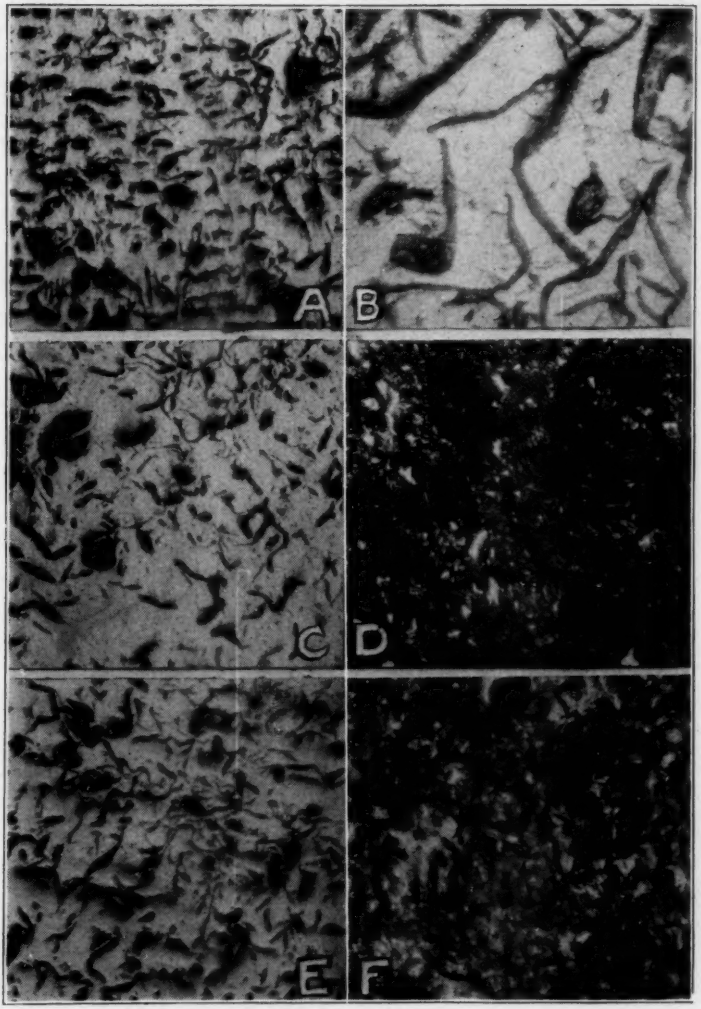

FIG. 13—*A:* TENSILE BAR. WATER QUENCHED FROM 1400 DEGS. FAHR., DRAWN AT 400 DEGS. FAHR. BRINELL 137, STRENGTH 31,750 LBS. PER SQ. IN. UNETCHED, 100X.

B: SAME AS *A*, BUT ETCHED WITH 5 PER CENT HNO_3, 500X.

C: CHROME-MOLYBDENUM TENSILE BAR NO. 1. WATER QUENCHED 1550 DEGS. FAHR., DRAWN AT 1040 DEGS. FAHR. BRINELL 341, STRENGTH 43,600 LBS. PER SQ. IN. UNETCHED, 100X.

D: SAME AS *C*, BUT ETCHED WITH 5 PER CENT HNO_3 IN ALCOHOL.

E: CHROME-MOLYBDENUM BAR, AS CAST. BRINELL 248, STRENGTH 39,500 LBS. PER SQ. IN. UNETCHED, 100X.

F: SAME AS *E*, BUT ETCHED, 100X.

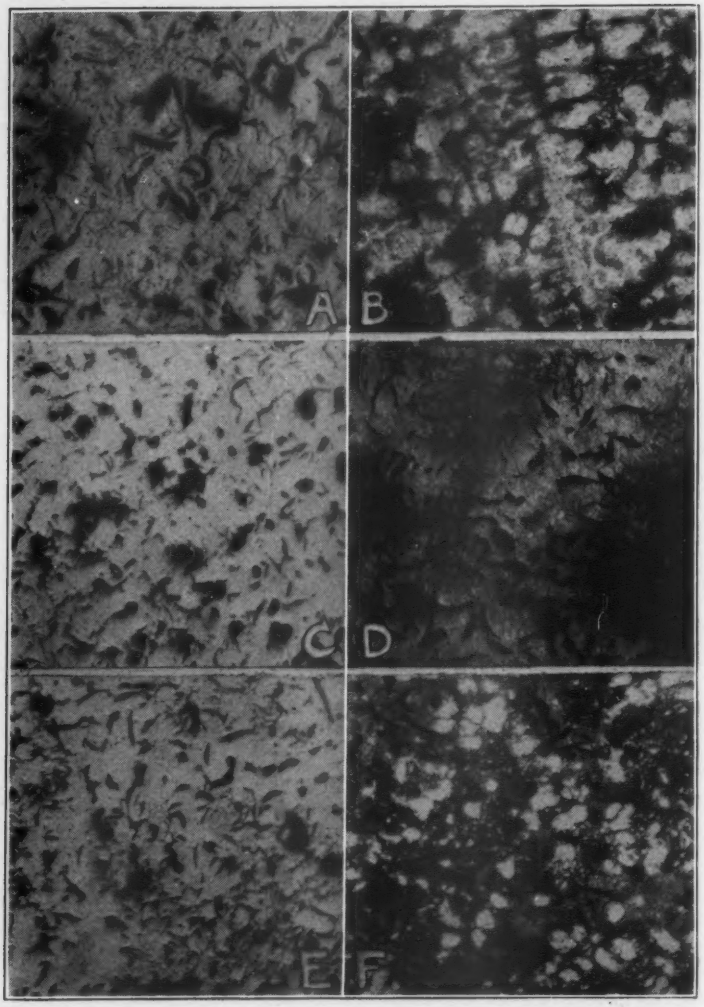

FIG. 14—CHROME-MOLYBDENUM BARS. *A:* WATER QUENCHED FROM 1460 DEGS. FAHR. BRINELL 197, STRENGTH 34,300 LBS. PER SQ. IN. UNETCHED, 100X.

B: SAME AS *A*, BUT ETCHED, 100X.

C: WATER QUENCHED FROM 1675 DEGS. FAHR. AFTER 2 HOURS AT 1775 DEGS. FAHR. ROCKWELL C HARDNESS 53. UNETCHED, 100X.

D: SAME AS *C*, BUT ETCHED, 100X.

E: WATER QUENCHED FROM 1375 DEGS. FAHR. AFTER 2 HOURS AT 1775 DEGS. FAHR. ROCKWELL C HARDNESS 20. UNETCHED, 100X.

F: SAME AS *E*, BUT ETCHED, 100X.

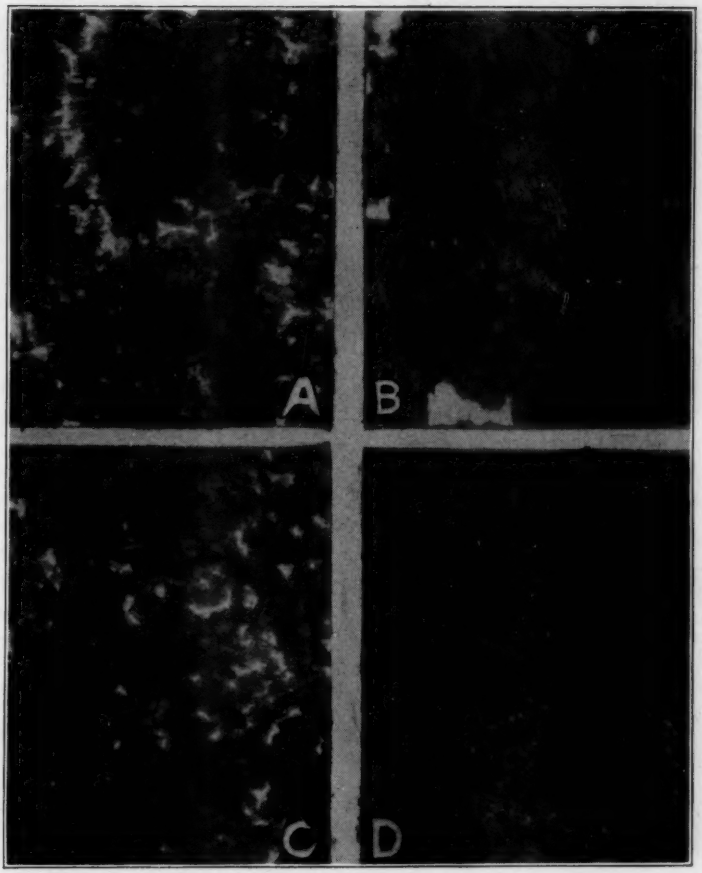

FIG. 15—CHROME-NICKEL-MANGANESE BARS. *A:* WATER QUENCHED FROM 1240 DEGS. FAHR. BRINELL 235. ETCHED WITH 5 PER CENT HNO_3, 100X.
B: SAME AS *A*, BUT 500X.
C: WATER QUENCHED FROM 1400 DEGS. FAHR. BRINELL 302. ETCHED WITH 5 PER CENT HNO_3. 100X.
D: SAME AS *C*, BUT 500X.

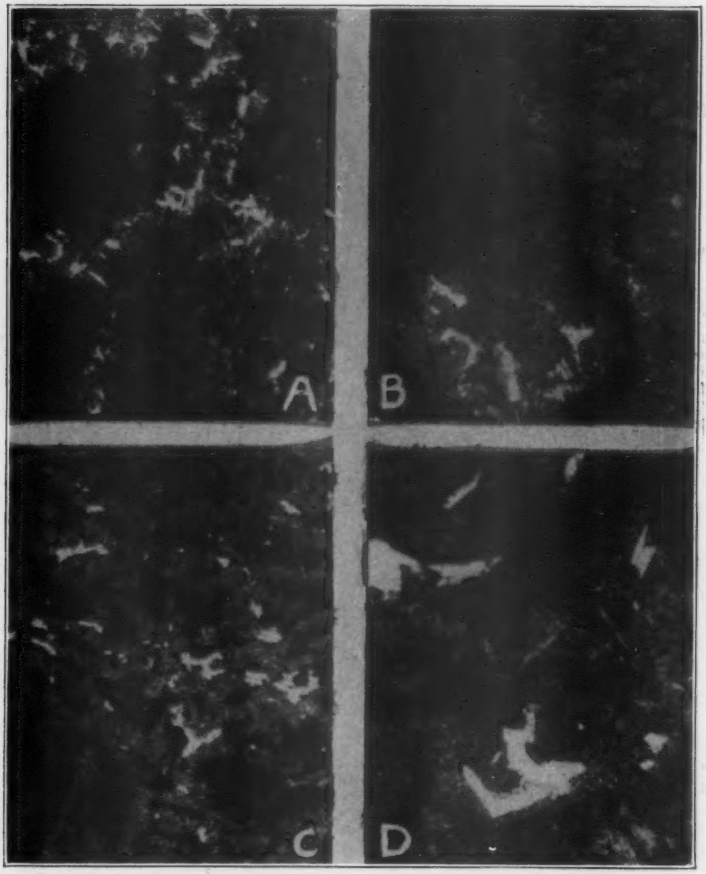

FIG. 16—CHROME-NICKEL-MANGANESE BARS. *A:* WATER QUENCHED FROM 1500 DEGS. FAHR. BRINELL 429. ETCHED WITH 5 PER CENT HNO_3, 100X.
B: SAME AS *A*, BUT 500X.
C:. WATER QUENCHED FROM 1550 DEGS. FAHR. BRINELL 461. ETCHED WITH 5 PER CENT HNO_3, 100X.
D: SAME AS *C*, BUT 500X.

44. Four A. S. T. M. arbitration bars which had an original brinell of 229 were heat treated as follows:

No. 1—Water quenched from 1550 degs. Fahr., drawn for 45 minutes at 1040 degs. Fahr.

No. 2—As cast.

No. 3—Water quenched after 25 minutes at 1460 degs. Fahr.

No. 4—Water quenched after 35 minutes at 1560 degs. Fahr.

45. These were tested (see Table 10) and, with the exception of bar No. 4 (which could not be machined), a tensile test was made on one-half of the broken transverse bar. The microstructure of this iron is shown in Figs 13*C* to 14*F*, inclusive.

46. We find here the same types of structure as in cylinder iron. Martensite is formed by quenching from above the critical point. Troostite and sorbite are found by quenching and drawing. Quenching below the critical point shows some graphitization, but the retarding influence of the alloys prevents its completion in short-time heats.

47. The tests on chrome-nickel-manganese cast iron were made on four 1-inch square bars with the compositions of Table 11. The critical range on both heating and cooling is shown in Fig. 8. The test was run on bar No. 2. The result obtained was checked by quenching samples of the bars on a rising heat and also by heating above the critical, soaking there for one hour and quenching at intervals as the furnace cooled. The results (Table 12) are shown graphically in Figs. 9 and 10.

48. Figs. 15 and 16 show the microstructures at different treatments. No graphitization is apparent in these pieces. The softening is due to the formation of lamellar pearlite from the original sorbitic pearlite.

Conclusions

49. The four main points determined are as follows:

(1) The relief of stresses below the softening point.

(2) The almost complete graphitization of the eutectoid cementite below the critical point.

(3) The solution of graphite above the critical point.

(4) The effect of alloys in decreasing the rate of graphitization.

50. Specifically, to obtain maximum relief of stresses with a minimum of growth and change of hardness, heat at 950 degs.

Fahr. and follow by slow cooling. To obtain dead soft iron, heat just below the critical, and air cool. In cylinder iron this will be about 1450 degrees. In chrome-molybdenum iron also it will be 1450 degrees, while in chrome-nickel-manganese iron a temperature of 1375 degrees should be used and at least double the usual time. Water or oil quenching may be used unless the sections are so complicated that cracks might result.

51. To obtain hard cast iron, heat to 1500 degs. Fahr. or above and quench in water. For irons with higher silicon, it will be necessary to heat much higher than this to dissolve enough graphite to give maximum hardness on quenching.

52. Increased strength in simple sections will be obtained by following the above treatment with a draw. The addition of alloys to the molten metal, or superheating the iron, may also be used for the same purpose. At present these are cheaper and more satisfactory than heat treatment for higher strength iron.

53. We have tried in this paper to show some of the results that may be obtained by heat treating cast iron. There is much work to be done on the different types of iron. The quantitative effects of silicon, carbon and manganese, as well as the alloys, should be determined. More work is needed on the relieving of stresses.

54. Probably the greatest field is in the study of the effect of variations in the cooling rate on the properties of various irons. Work on this subject should lead to great advances in high-test iron.

DISCUSSION

ORAL DISCUSSION

O. W. POTTER:* Mr. Walls, did you say that you rough machine these castings before you anneal them?

F. J. WALLS: We semi-machine our sleeve castings, that is, inside and out. Most foundrymen are familiar with the shape of a sleeve, as simply a cylindrical shape. We take about a 3/32-in. cut off the inside and the same off the outside.

We do this because that is probably where most of the stresses are. Then, too, we have machining stresses that we want to relieve also, or strains rather than stresses, because that is what is being put in there. It is the stress that forms the strain. But, in any casting, most of the stresses probably will be found on the outside surface, due to the cooling effect of the mold.

*University of Minnesota, St. Paul.

O. W. POTTER: I wonder if, in this operation, you are not sacrificing some time that could be gained by annealing first and removing some of the difficulties encountered in the scale. That is an open question. That has been the practice, but I question whether that is the right side, too. I would anneal first.

F. J. WALLS: I do not believe you can relieve or eliminate very much scale at 950 degrees, or ease up on your machinability for your tools. A small amount of silica grains form in the surface of the casting which might be loosened up by that temperature.

We do not anneal those castings for that machinability; we try to make them machinable without. We kill two birds with one stone—we are trying to relieve the casting strains and also the machining strains. There has always been a question as to whether there are not just as many strains set up by improper machining or "hogging" the cuts in the machine shop as there are in casting the iron in the mold in the foundry.

J. M. SAMPSON:* I thoroughly agree with the conclusion in the author's paper. On our large castings for the past ten years or more, the regular practice has been to anneal at about 950 to 1000 degs. Fahr., or 525 degs. Cent. Many of these castings run over thirty feet long, and up to 60 or 70 tons in weight. Unless the strains are removed, the castings certainly will not match up after two, three or four pieces are put together on the assembly floor.

During the last two or three years, in making certain small castings, our regular practice has been to anneal up as high as 850 degs. Cent. (1562 degs. Fahr.), and in some cases to 900 degs. Cent. (1652 degs. Fahr.)

We found we got one-third to possibly 40 per cent reduction in strength, but our brinell hardness was what we were after, and that has been maintained right along around 180 to 200 brinell.

F. J. WALLS: If you got 180 to 200 brinell after heat treating at 1550 or 1600 degrees, what was the brinell originally?

J. M. SAMPSON: In the body of the casting and the heavier sections of that particular casting, the brinell was about 215. On the edges, where very thin winged, they were practically white or mottled.

F. J. WALLS: Was the hardness in the other parts of your casting about 140—possibly a little lower than 140?

J. M. SAMPSON: No, in the body of the casting, on a section cut through the heaviest part, the softest portion would run approximately 180 brinell.

F. J. WALLS: How many hours did you anneal at the stated temperature?

J. M. SAMPSON: We held at that temperature for about one to two hours. Those were straight carbon irons.

F. J. WALLS: It seems to me you would have no pearlite left.

J. M. SAMPSON: It was entirely pearlitic. It is accelerated cooling; it is not cooled slowly. We have a fan mounted on the electric furnace

*General Electric Co., Schenectady, N. Y.

and the castings themselves, to prevent oxidation, are put into containers which are covered and the cracks luted with clay. There are several vents in the top of the roof which are opened up, and the fans are started slowly and gradually accelerated.

F. J. WALLS: What silicon content did you have in your iron?

J. M. SAMPSON: The carbon content will run about 3.10 per cent; silicon, about 2.30; manganese, about 0.55 to 0.65; phosphorus, about 0.38.

MEMBER: Mr. Walls, what is your theory on the breaking down of valve seats in cylinder blocks that have apparently been overheated?

F. J. WALLS: That is a matter of design on cylinder blocks more than anything else, I believe. Design has as much to do with the problem as anything else.

MEMBER: What will overcome it? The design could not very well be overcome.

F. J. WALLS: Perhaps Mr. MacPherran's paper will answer that, as yours is probably an alloy problem. Increase the temperature at which graphitization takes place.

MEMBER: Would a lower total carbon in the casting materially affect it?

F. J. WALLS: In all probability, yes. There is considerable room for discussion here, as anyone who has had experience with valve seats will agree. Some automobile companies are pressing in seats, using silicon-chrome steels, and so on. Fortunately, in our engine we do not have valve seats.

A. J. FIELD:* We in England are not very much interested, perhaps, in the question of heat treatment for the relief of strains, but we are very much interested in heat treatment for softening. Mr. Walls, what material are your castings covered with to prevent oxidation, both at this temperature and at higher temperatures, where softness is desired, and what precautions are taken to prevent oxidation so there will be no hardness in machining?

F. J. WALLS: What is desired is oxidation to make the castings machine easily. Oxidize the iron there and let the grains of sand fall off. That has been our experience.

A. J. FIELD: We find that if the atmosphere is at all oxidizing, very often we get a scale of oxide which is difficult to machine.

F. J. WALLS: That is possible with prolonged heating. We do not cover our castings. We anneal them in muffle-type furnaces with just the normal atmosphere—we do not use any hydrogen or anything like that.

R. S. MACPHERRAN:† We anneal our castings in the open furnace and get no hard scale. We have no difficulty in machining. Perhaps your atmosphere is deoxidizing, Mr. Field.

We anneal our castings in an ordinary muffle and there is no appar-

*British Aluminium Co., Ltd., New York.
†Allis-Chalmers Mfg. Co., Milwaukee.

ent hard scale formed. We anneal a great many of our large castings for relief of machine strain and once in a while to make them softer, but they are always annealed in an open muffle furnace, oil fired.

J. T. MACKENZIE:* One point should be mentioned in connection with Mr. MacPherran's paper: Because a piece of cast iron at a given temperature and a given time does not lose but 30 per cent of its strength, that does not necessarily mean that that piece will not lose more than that when in service where the condition of loading is probably one of reverse stress. As Mr. MacPherran has shown, this is highly important in corrosion. Where neither corrosion nor the fatigue stress in themselves would destroy the piece, the sum of the two will destroy it at a fairly rapid rate, and this is entirely possible in working parts subjected to temperatures much lower than that described by Mr. MacPherran.

D. P. FORBES:** Mr. Walls, did you make any determinations, in quenching a piece of cast iron for hardness, as to the change in size or change in dimensions of the piece?

F. J. WALLS: No, we did not. We were particularly interested in hardness and strength. We did not measure change in volume. There is considerable room for research along those lines, however.

H. P. KIMBER:† We make our castings in permanent molds, and the average shrinkage has been approximately 0.15 per cent when the castings were quenched in oil at a temperature of 1600 degs. Fahr. That is a soft iron: 2.5 per cent silicon, 3.5 per cent carbon and about 0.55 or 0.60 per cent manganese.

On the annealing and scale question brought up by Mr. Field, we anneal all our castings in a continuous annealing furnace. Those castings which are used for rapid machining purposes, where we want a dead-soft anneal, we anneal at 1600 to 1625 degs. Fahr. for one-half hour. We get a good scale on those castings—one which tumbles off easily. For castings that require some strength, we anneal at 1560 degs. Fahr. for one-half hour. They also scale considerably, and the scale tumbles off readily.

R. M. ALLEN:†† There are, of course, two distinct reasons for considering the effect of heat on cast iron as presented in these two papers—one, the relieving of stresses, and the other, determining the effect of heat on irons which have to withstand considerable temperature.

This latter is a vital question. Even since leaving New York, I received a telegram asking my opinion as to whether a certain piece of apparatus would operate satisfactorily at an elevated temperature. Such questions are coming up constantly.

It might be of interest to discuss the reason why various irons stand up or fall down or behave as they do under high temperatures. I do not want to start a discussion among the two schools as to whether or not the double diagram is correct and whether the iron-graphite is the stable

*American Cast Iron Pipe Co., Birmingham, Ala.
**Rockford-Northwestern Malleable Corp., Rockford, Ill.
†Holley Permanent Mold Machine Co., Detroit.
††Bloomfield, N. J.

system and the other the meta-stable, but I do believe that in the solution of this question lies the final answer to the way irons behave under heat treatment.

Personally, I might say that I am strongly in favor of the single system, and I think it will ultimately be shown to be correct—that is, that iron iron-carbide is the stable system and that graphite is only thrown down when there is present some element such as silicon, nickel, copper, aluminum or magnesium, even in very small quantities, which tend to precipitate carbon and, in the second place, in the presence of graphitic nuclei, to start the precipitation.

Be that as it may, we can subdivide the elements into two groups, one of which aids in precipitation of graphite, such as those mentioned, while the other tends to neutralize the effect of those that tend to throw out graphite. This neutralizing group includes such elements as chromium—undoubtedly one of the strongest in this respect, as has been so well proven in Mr. MacPherran's paper—and others such as manganese and sulphur.

If this is true, then it gives us, as development engineers, an opportunity to determine how we shall accomplish any given result. That is, if we have to develop an iron that requires withstanding an excessively high temperature, we may have to sacrifice certain characteristics of the iron in producing the result. At least, however, we can balance those elements which retard graphitization against those which aid it, to such an extent that for the time cycle and the temperatures which are involved, we perhaps can achieve the desired result.

Both of these papers are helpful steps toward the ultimate solution of this problem. I only hope that Mr. MacPherran goes further and works out a set of graphs for a whole series of irons, showing to what extent one element can be balanced against another so as to result in an iron practically stable, which will maintain its strength and hardness for any length of time up to a temperature limit where the carbon will be precipitated out.

HENRY KOHNLE:* Regarding the breaking down of the valve seats in an automobile cylinder block, I want to mention my own experience. It is not a technical one, it is not written up in fancy figures or anything like that, but I have been doing quite a bit of automobile work and work of a similar nature, such as gas engine work, etc.

I am speaking about an air-cooled internal combustion cylinder used in a Delco light outfit. They have had a great deal of trouble with their exhaust outlet breaking down. Due to the intense heat of the gases passing through the exhaust port, it will break down much more rapidly than the intake valve.

They sent the pattern around to five different foundries to find out who was making the best iron. We had a try at it and eventually got the job. Why? Because our casting stood up the best of the five.

The way we did that, we poured it with what we call semi-steel, a 20 per cent steel mixture in the mix. To that we added 2 per cent of

*Superior Casting Co., Dayton, Ohio.

fine, laminated steel that we get from concerns making small motors. This is sheet metal that forms up in the armatures of the motors, and it comes in odd shapes.

This steel contains about 1.5 per cent silicon, according to our analysis, and we used it—about 4 per cent—in the ladle if the iron was hot enough. If it was not hot, of course, we would not dare to use so much; but if it was hot enough to melt 4 per cent, we put it in. We poured those castings with that laminated steel in the mix and we had very fine results.

MEMBER: Mr. Allen, what did you mean when you said, "sacrificing certain qualities of a casting?" In my judgment, many things can be attained by sacrificing machinability, but what are you going to do then?

R. M. ALLEN: My thought in using that phrase was merely to qualify what I was saying. There are limits, as regards each characteristic of the iron, to which it is possible to go in developing one which would not fall down at a given temperature.

Machinability might be one of the things that would have to be sacrificed in order to secure stability at high temperatures, or it is possible that it might be necessary to make an iron which would be relatively brittle. Several characteristics might have to be sacrificed to some extent to effect the best compromise. I did not have any specific example in mind when I made that statement.

MEMBER: Mr. Allen, is it your judgment that it would be possible to make an original casting, with the exception of machinability, to anneal it and get the machinability and then, by some sort of heat treatment, to bring it back to the state that you desired?

R. M. ALLEN: I would not undertake to say what the limit might be. Our knowledge of cast iron as a whole is really only in its infancy. The trouble is that we are apt to think of cast iron as a relatively simple compound. We try to graph it and make it fit into the iron-carbon equilibrium diagram, although some go so far as to make it a ternary compound.

Actually, ordinary cast iron is not a ternary compound—if anything, it is a senary compound, with six elements, and presents a problem there that is somewhat like chess.

I was talking to some friends last night about playing chess. Chess is an unsolved problem—"Which to move and win?" Cast iron, too, is an unsolved problem today—"What is the limit to which you can go with it?"

DR. F. W. MEYER: In both the papers presented and in the discussion, the results given were only with regard to expansion and to the change of hardness of cast iron. A very important factor was disregarded—the growth of cast iron. Growing of cast iron means the tendency to enlargement of volume in heating at higher temperature, especially due to repeated heating and cooling.

I like to refer to Professor Piwowarsky's publications on the subject of growing of cast iron and his very extensive conclusions. A pearlitic iron shows low tendency to growth. The finer the size and distribution of graphite, the more the material is protected against growth due to

oxidation. It seems that the air or vapor, etc., starting the oxidation or corrosion, or both of these combined, penetrates along the graphite flakes.

In designing a casting, especially in the determination of the metal lines, we must consider the influence of cooling rate upon the structure in such a way to guarantee in the casting even distribution and size of graphite. The composition of the mixture, the heat treatment in molten condition and the cooling rate can be regulated to obtain fine graphite precipitation. Recent experience in Europe seems to prove that the more oxides are included in a cast iron, the more rapid is the growth under atmospheric conditions.

Coming back to the breaking down of valve seats, it is possible that it is a result of constant heat treatment under working conditions. It was suggested to heat treat such castings in order to take out the internal strains; but we have no guarantee that even after having heat treated a casting, due to the constant heat treatment in operation, no internal strains are newly formed on account of growing. Cementite may be decomposed and, in vapor or oxidizing atmosphere, oxidation will take place.

These few points show the necessity of their consideration at any time when castings subjected to heat treatment under working conditions are breaking down.

J. S. VANICK:* Mr. Walls, concerning the average growth and average expansion in Fig. 2, is the growth a volume change, and how was it obtained?

F. J. WALLS: We measured the growth before cutting, and then the expansion taking place when a small section was cut off from the heavy section.

J. S. VANICK: I do not quite understand that matter of growth. Does the diameter of the section enter into it?

F. J. WALLS: Growth there is measured before the bar is cut, while expansion is the distortion that takes place when the little bar is cut off. They are not related. The strain is what we are measuring.

Probably it would be very interesting to measure the stress at that point, or the amount of pull required to pull that back to the same place. Probably there are a number of interesting figures involved.

J. S. VANICK: Perhaps "growth" is a little too broad a word to use for the type of test you are making. The length increase should be called warpage or distortion, for the reason that cast iron and also other cast materials are liable to adjust internal or casting stress after the preliminary heating in such a way that either an expansion or contraction may result.

In the case of a long, round bar the heating could produce an increase in length, accompanied by a decrease in diameter with no resulting changes in volume or growth.

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*International Nickel Co., New York.

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